HANDBOOK

OF

BUILDING CONSTRUCTION

VOLUME II

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HANDBOOK
OF
BUILDING CONSTRUCTION

DATA FOR
ARCHITECTS, DESIGNING AND CONSTRUCTING ENGINEERS, AND CONTRACTORS

VOLUME II

COMPILED BY A STAFF
OF FIFTY SPECIALISTS

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SECTION 5
CONSTRUCTION METHODS

SYSTEM AND CONTROL IN BUILDING

By A. G. Moulton

It can be said that modern construction methods owe their supremacy to the mistakes of the past and an equally plausible assumption follows that the mistakes of the present will be of similar if not greater assistance to the builder of the future. A recognition of this fact by many of our representative builders has inclined them, in an earnest effort to profit by their own errors, to undertake a more serious and systematic study of the problems coming before them than they were wont to make in the past. Feature by feature, each feasible scheme has been taken up and separately analyzed; every branch of industry has been called upon for that which would seem to assist or be of benefit and every science has been enlisted for that which would be helpful, until today there stands a profession in all that the name implies to supplant what was only a trade of yesterday.

The first result of such serious study has been a general systematizing of the essential forces and efforts, both as applied through the office in preliminary preparation as well as in actual field operations. System implies control, and this is now obtained through the assistance of two highly important documents: (1) the "time schedule;" and (2) the "working estimate."

1. The Time Schedule.—Every building operation before reaching the construction stage should be placed on a definite time schedule, with predetermined dates for the arrival and departure of each individual trade that will enter into its construction. In form it may not be unlike the railroad folder of common usage. A more forcible resemblance may perhaps be found in the discovery that it is equally as destructive to the progress of a building to assign two conflicting trades to the same period as would obtain were two trains to attempt the same stretch of track concurrently.

1a. Elements of the Time Schedule.—A properly prepared building schedule will assign to each trade or operation four definite dates:

1. The date on which subcontracts or purchase orders should be placed in order that the materials involved may be properly and economically prepared and deliveries synchronized to keep pace with the leading trade. On a well-analyzed operation, such a thing as waiting for materials is quite inexcusable; not only will the continuity of the trades be disturbed, with consequent hardship to other departments and lines not to blame, but more often than not, a permanent delay to the building's completion will ensue. This directly affects the owner's interest, and on many enterprises, where the investment assumes vast proportions as the date of completion approaches, even so little as a day's delay may be a matter of serious financial loss. Equally so, it is important not to crowd a job with materials before the operation is ready. To do so means additional expense of rehandling and temporary protection, to say nothing of the handicap placed on other trades by causing them to work over and around stored materials.

2. The latest date on which all information inclusive of designs, scale details, and approved shop drawings must be in the hands of the subcontractors or shop, in order that they may intelligently prepare or fabricate the materials and meet promised delivery. With the importance of this date recognized by the architect or designing engineer, little or no difficulty should be experienced in adherence thereto. On the other hand, without this very close cooperation, many serious set-backs will creep into the building operation and constant watchfulness may be required on the part of the builder to protect the schedule at this point.

3. The date on which actual field work at the building should commence. Here again, delays are dangerous. The failure of one trade to take its appointed place at the time designated will either throw back all succeeding trades a corresponding period or will result in the confusion of two or more trades trying to operate in the same space, until the delinquent one has speeded up to resume his normal station. While the exact sequence in which the various trades should be brought upon the work is in a few instances debatable, their position as a rule is generally predetermined by the relation one bears to the other. When this relationship is not clearly defined, such as between

steam or plumbing risers and floor arches of steel frame buildings, or between plaster ceilings and cement or marble floors, resort must be had to local custom, and the adaptability of the tradesmen involved to that procedure which would seem the most economical in time and money. Other things being about equal, that method resulting in the least total time expended on the structure should always receive the decision.

4. The date on which all field work should be completed; a delay here may or may not be so vital, dependent on whether succeeding trades are held up thereby in the completion of their work.

A slow or faltering trade is always a detriment to any building enterprise, and it is for the quick detection and prompt cure of such symptoms that the time schedule serves its most important purpose.

1b. Stages of Building Operations.—The facility and practicability with which a time schedule may be prepared is dependent quite largely on the experience and general knowledge of trade sequences possessed by the compiler. For an initial try-out it is well to conceive the building as divided into the three periods or stages of construction into which it quite naturally groups itself. They are as follows:

(1) Foundations and walls to grade.
(2) Superstructure without finishing trades.
(3) Finishing trades.

First Stage.—For the first stage, conditions will be found to vary so with each different structure that set rules do not readily apply. Preparation of site, with possibly a wrecking operation, excavation, foundations, sheet piling, shoring, piling, caissons, steel grillage, and walls to grade may all be involved. In ascribing time values to this class of operations, only an intimate knowledge and study of local conditions can be relied upon. Each individual operation should be analyzed separately, and that starting date established which will result in the greatest harmony to the whole. It should be borne in mind that at this stage the working space is greatly restricted, and the surrounding conditions for the receipt and storage of materials are apt to be at the worst. In order to compensate for unforeseen contingencies, as much slack as the total time allowed for the building will permit should be allotted to this stage of the operation; even at the expense of a sensible tightening up on the schedule for the balance of the work. A rough-and-ready check found useful by the writer is an allowance of 2 ft. per week, the figured distance being the depth to which the footings project below grade. Such a check is not accurate on very deep foundations, such as are met with in Chicago practice with caissons extending 90 or 100 ft. below grade, but more directly applies to rock work and foundations of medium depth as found in the East and elsewhere.

Second Stage.—The second stage, that of the superstructure, is controlled in time values by the three basic trades involved:

1. The supporting steel skeleton, or, if wall bearing construction, the exterior walls themselves.
2. The arches or floor construction.
3. Dividing walls or interior partitions.

All other roughing trades are collateral with or dependent upon one or the other of the aforementioned principal lines.

In the further discussion of the time schedule and its preparation, reference will be had to the steel frame or strictly fireproof type of building as generally found embodied in the modern hotel or office structure. Being more complex in the number and variety of trades involved, it will serve as the best illustration. Schedules for other types of construction can be evolved by similar methods, simply eliminating those trades which do not pertain. On this type of construction 4 to 5 days per story of height is the usual time allowance for erection of the steel frame. It is to be noted that on the above basis the area of the building bears no direct function to the progress desired. It has an effect, however, on the type of equipment to be chosen, which will be referred to later. As an illustration, a 12-story hotel or office building would be allotted from 48 to 60 days in which to carry the steel work from grade to completion, which includes the time required by the steel erector in getting his forces and equipment away from the building. The collateral trades dependent on the steel work should be started concurrently with it or at intervals of a few days—due caution as to the safety of the workmen involved, and the proper sequence to prevent the covering up of uncompleted work by other trades being observed.

The second controlling trade embraces the floor construction, or arches. A safe rule is to set this down to start from 25 to 40 days after the start of the steel; and the third controlling trade, or interior partitions, the same period after the start of the floor arches. In each instance the dependent trades will be assigned their places in manner similar to that described for those following the steel.

Third Stage.—For the finishing trades, or third stage of the building, conservative practice permits an allotment of from 90 to 120 days after completion of steel, indicating about 40 days after completion of interior partitions.

1c. Total Time Involved.—Reverting again to a 12-story structure, and assuming that the foundations extend 20 ft. below grade with basement included, the time schedule will now have reached somewhat the following values:

Foundations: 10 weeks or 70 days	70 days
Steel frame: 4½ days per story, or	54 days
Arches finish after steel	30 days
Partitions finish after arches	30 days
Finishing trades 100 days after steel	40 days
Total time	224 days or 7½ months.

TIME SCHEDULE

THOMPSON-STARRETT COMPANY

Class Office **Building** Smith **No.** 875 **Date** ____

Office schedule				Job schedule	
Architect's drawings to let contract	Contract must be let on or before	All details for sub-con.	Work	Start	Finish
			1 Steel drawings		6-7 28
			2 Architect's drawings		
6 1 28	6 1-28	6 10-28	3 Wrecking	6 1-28	6 20
6-1	6-4	6 15	4 Excavation.	6 10	7-30
6 1	6 10	6-20	5 Drains and water	6-20	7 10
			6 Caissons—piles		
6-15	6-15	6-25	7 Foundations - concrete	7 10	8 25
6-15	6 15	6 25	8 Walls to grade	7 20	8 30
6-15	6 15	6 25	9 Waterproof--walls	7 20	8 30
6-5	6 5	6-15	10 Grillage—column bases	8 15	8 30
6-5	6-5	6-15	11 Steel erection—stack	9-1	10 25
6-20	7 10	7 20	12 Ornamental iron—stairs—plain	9-10	11-25
6-20	7 10	7 20	13 Ornamental iron—finish	12 20	3-15
6 20	7 10	7-20	14 Elevators—guides -temp. car	10 15	11 22
6 20	7 10	7 20	15 Elevators—car—signal—test	12 20	3 15
6 20	7 10	7-20	16 Boilers—temp. heat	10-10	12-10
8-1	8 20	8-30	17 Pump—tanks	11 1	11-30
7-1	7 20	7 30	18 Arches	9 12	11-15
6 20	7 10	7 20	19 Plumbing—gas—rough test	9 10	1-8
9 1	9 20	9-30	20 Plumbing—finish -fixtures	12 20	2 25
6 20	7 10	7 20	21 Heat—ventilation rough	9 10	1-8
9 1	9 20	10-30	22 Heat-regulation-finish	12-20	2-25
6 20	7-10	7 20	23 Electric-rough—temp light	9 10	1 8
9-1	9 20	10 30	24 Electric—fixtures	12 20	2-25
7 10	7 30	8 10	25 Common brick masonry	9 25	12 20
7 1	7-20	7-30	26 Granite	9 20	9 30
			27 Bluestone		
7-1	7-20	7-30	28 Limestone—marble exterior	9 25	12-20
7-1	7-20	7-30	29 Terra cotta	12 5	12 20
7-1	7 20	7 30	30 Face brick--enameled	10 1	11 10
7-1	7 20	7 30	31 Special brick-mould--fire-hollow	10 1	11 10
7-1	7 20	7-30	32 Wood frames—sash--pulleys	9 25	12 20
7-1	7 20	7-30	33 Metal frames-sash—pulleys	9 25	12-20
7-20	8-10	8 20	34 Weights—chains	10 10	12-20
7-20	8 10	8-20	35 Glass	10 10	12 20
8-1	8 20	8 30	36 Roof cover	11-15	12 20
8 1	8 20	8 30	37 Sheet metal	11 15	12 20
8-1	8 20	8-30	38 Bucks	10 20	1 5
8-1	8 20	8-30	39 Strips and fill	10 20	1 5
8-1	8 20	8 30	40 Partitions and furring	11 10	1-20
8-1	8 20	8 30	41 Grounds and lath	11 25	2 5
8 20	9 10	9-20	42 Plaster—plain	12 10	2 25
8-20	9 10	9-20	43 Plaster—ornamental—caen scag	1 10	2 25
9-1	9 20	9-30	44 Marble walls--tile	12 20	3-5
9 1	9-20	9 30	45 Marble floors--tile—mosaic terrazzo	12 30	3 15
8-10	8-30	9-10	46 Hardware—finish	12 20	2 20
8 10	8-30	9-10	47 Trim--wood	1 10	3 25
8-10	8-30	9-10	48 Trim--kalemein	1-10	3-25
8-10	8-30	9-10	49 Paint—decorations	2 1	4-5
8 10	8 30	9 10	50 Finish floor--wood--cement	12 20	3 5
9-1	9 20	9 30	51 Paving—sidewalk—curb—bmt. floor—w.p.	2 20	3 20
9-1	9-20	9 30	52 Revolving door	3 1	4-10
8-10	8 30	9 10	53 Mail chute	11-5	3-10
			54 Vault work—bank		
6-20	7-10	7-20	55 Sweeping—pneumatic	9 10	2 25
6-20	7-10	7-20	56 Sprinkler	9 10	1 20
6-20	7-10	7-20	57 Ice plant	9-10	1-20
			58 Laundry—kitchen		
			59 Engines—generators—motors		
			60		
			61		
			62		
			63		
			64 Finish building—schedule time	6 1 28	4-10-29
			65 Finish building-contract time		5 1-29

1*d*. Specimen Time Schedule.—A specimen time schedule as completed and used in actual practice is shown on p. 817. The dates shown in the two right-hand columns are those worked out first by methods just described; those in left-hand columns, the purpose of which has already been referred to, are then deduced from the starting dates. The accuracy with which they may be established depends almost wholly on the exact knowledge possessed by the compiler of modern shop practice and, to a lesser degree, on his acquaintance with the local customs prevailing in the locality at which the different branches of the work are being fabricated.

1*e*. Graphic Time Schedule.—For the purpose of recording the actual progress attained by the job from week to week, the time schedule shown on p. 817 is often revamped in graphic form, with the major lines of work set down in the left-hand vertical column and the allotted time for each such trade extended across the sheet in heavy lines drawn to scale of

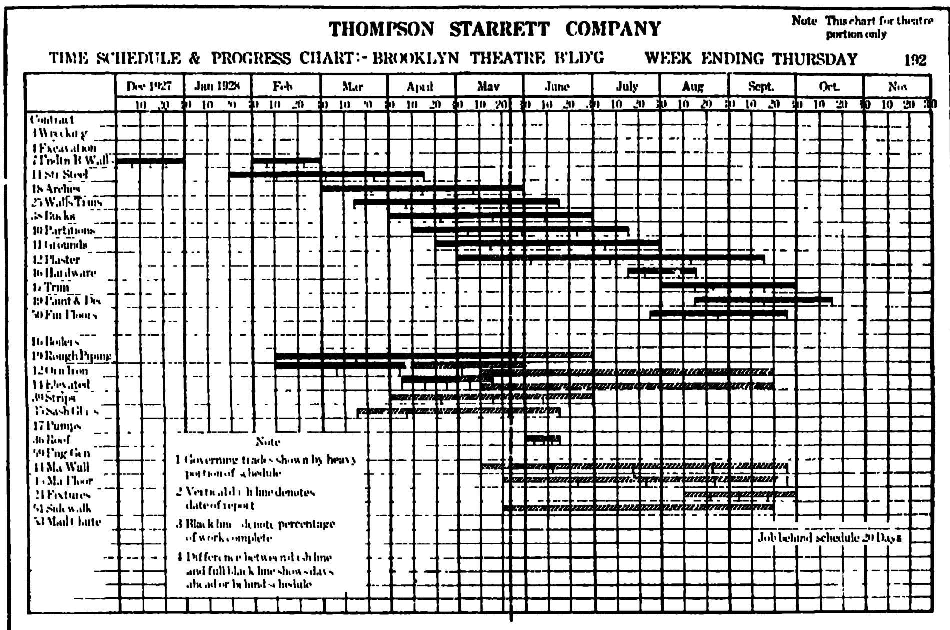


Chart No. 1.—Graphic time schedule.

days or weeks. In such form, the import of the schedule is perhaps the more easily grasped, for not only does it indicate the starting and finishing dates but it also shows the number of trades which should be working concurrently and the percentage of each which should be completed at any particular time. These graphic schedules, if prepared in blueprint form from original tracing and issued weekly, with the percentage of progress to date for each trade indicated on same by colored crayon or heavy full line, will be found of much value in promptly detecting impending trouble. On the date of issue a vertical red line or vertical dashed line is dropped from the proper position on the time-scale line, and the distance by which the horizontal colored or heavy full lines then fall short or overlap indicates at a glance which trades are trailing and the extent thereof. A specimen of such a graphic time schedule is shown above.

1*f*. Time Schedule as a Plan of Operation.—The time schedule after completion should be freely circulated among all interested departments. To the designing engineer or architect, it indicates the precise sequence and the latest date at which all information including

approvals must be available; to the contract department it indicates the latest dates on which subcontracts may be safely let; and it also supplies the starting and completion dates to be incorporated therein. It furnishes the purchasing department with exact information on which to base future deliveries of stock materials; to the expediting and traffic departments it is indispensable in following up the preparation, shipment, and delivery of fabricated materials from distant shops and factories; to the building superintendent it should be his daily guide and reference for the coördinating of all field activities.

2. The Working Estimate.—Second only to the time schedule as a controlling feature is the "working estimate." Some authorities will be found who give it preference on certain operations, believing that where time is not specifically mentioned as the essence of the contract, and strict economy only the end to be gained, a time schedule implying speed will have excessive costs attached thereto. A little thought, however, will dispel such a theory when it is recognized that a properly prepared time schedule does not make for speed at the expense of economy but rather holds its strength through its requirement for orderliness—in itself one of the fundamentals of economics. Through its harmonizing influence, many a valuable day will be retrieved to the owner to become a revenue producer, and at a lesser cost to the operation as a whole than if the work was carried on without its beneficial guidance.

2*a*. Basis of Working Estimate.—The working estimate may be based upon data already secured through preliminary cost estimates of the work but is more generally the result of a careful re-check on all quantities, taken direct from the plans after the award of a contract.

For those lines of work on which the builder's own forces will be employed, the quantities of material or labor involved will be set down in conventional terms against which the selected price units will be applied and the whole extended into dollars and cents. This is carried out trade by trade, the greatest amount of detail being observed to ensure to the fullest extent the elimination of all possible errors, and holding those that might occur to the minimum value.

If it is deemed desirable to have a complete schedule equalling the total allowance for the building operation, there will be added to the above figures the various suballowances for those lines of work which are to be purchased in their entirety, commonly called subletting.

2*b*. Standard Manual for Cost Data.—In order to standardize the work and ensure a more accurate and systematic collection of the cost data by field material and time clerks, it has become common practice for the builder to prepare a standard or manual, covering all possible subdivisions of work on which costs will be required, each branch and subdivision of same being indicated by a code letter or combination of letters and figures. The characters of this abbreviated index are then used to indicate disposition on all team tickets or other material receipts as well as subdivisions of time on daily time books, payrolls, etc.

The working estimate can be of value only to the extent of the intelligence with which it is utilized. To check same against actual results obtained on an operation after the work in question has been installed and completed can be productive of no value except possibly in relation to future work of similar character. To secure the full possibilities, some comprehensive system of cost recording is essential; data as to progress made, materials used, time involved, etc., should be collected daily by the field clerical forces with the results tabulated in weekly or semi-weekly reports. Where the volume of work in any particular line is large and fairly constant in its character, weekly reports will probably fulfil every requirement, but where the volume is small or the conditions under which it is proceeding are constantly changing, the semi-weekly or even daily reports should be prepared. The comparison of these reports with the working estimate and the interpretation of the disclosures therefrom by the building superintendent, or whomsoever may be making the comparison, can be beneficial only to the extent of his thorough understanding of the factors with which he is dealing. He should never fail to realize that the working estimate treats of averages only and that to draw a true comparison, the particular parcel of work under scrutiny if greatly at variance from the average, should be modified correspondingly by proper allowances before judgment is rendered.

A type of estimate more logical in its application, and at the same time slightly less difficult in preparation, is one in which the allowances are expressed in hours of labor rather than in terms of value. It recognizes the theory that the rate of wages applying to any particular locality is generally on a more or less established basis and beyond the province of the organization to change or alter. By limiting the unit of measure to the expected output per hour or day of laborer or mechanic, the field organization forces may be held accountable only for those factors over which they have admitted control. Another advantage lies in the far greater readiness with which such terms are accepted and made use of by foremen and other employees. An allowance of 80 brick per hour on a certain piece of masonry would be understood by all and is easily checked against by the simple operation of dividing the number

of brick laid during any selected period by the number of mason hours employed; whereas the same allowance expressed in terms of $12 per thousand is to the average individual quite a complex problem to check against except to those who have had previous estimating or cost-preparing experience.

3. Daily Reports and Diaries.—A third instrument essential to every building operation, but of lesser importance as a controlling feature, is the daily report or diary. This is prepared in the field and written up for each and every day, Sundays and holidays included. Each report should be numbered consecutively from start to finish of the operation so that the latest number will always indicate the duration of the job in days up to that point. Outside of certain essentials—such as weather conditions prevailing, the total number of employees, classified by trades, mention of any unusual mishap or accident, and the visitation of important personages—the scope of the diary may be varied by the responsible head to suit the particular work engaged upon. The best results will be obtained if these reports are personally prepared by the superintendent in charge, the assurance being thus gained that he is actually in touch at all times with every feature and detail of the operation. If, due to the scope of the work, this is found to be impracticable, he at least should sign the reports and see that they are transmitted to the main or home office at the end of each day.

PREPARATION OF SITE

By A. G. Moulton

It can be assumed that certain essential information, locating the proposed structure both horizontally and vertically with relation to known references, will be clearly indicated on the plans and sections previously prepared by the designing engineer. Horizontal distances given in feet and inches between opposing lot or building lines, the angles formed at their intersection, and the elevation of the first floor with reference to existing grade or some assumed datum comprise the information commonly given. In addition to this, the structure as a whole will generally be tied up by a figured dimension or dimensions to some established line or point. This may be an adjoining building, a party line, a street intersection or simply a stake or hub, should the site be an isolated one.

4. Location of Reference Points.—The first step by the field engineer should be to locate the reference points, consulting with such municipal departments as may be interested to inform himself as to the system of local grades and any existing ordinances that would call for formal permits, such as street obstructions, vault excavations, sidewalks, etc. Offset stakes or batter boards will be established for all corners or changes in direction of the building lines, care being exercised so to locate them that they will not be readily disturbed during the excavation period. One or more bench marks will be set up at convenient points against which all future building levels will be checked. The careful engineer will find time to re-check at frequent intervals all batter boards and benches until foundation operations have reached a point where there is no further danger of ground movement or other disturbance, and he will in particular make a re-check of all lines and corners before permitting any masonry work of foundations to proceed.

If the foundations are to project to some depth below the street or normal ground level or are in moving ground or apt to be of a hazardous nature, he will establish a series of benches on one or more piers of each of the adjacent buildings, also on all surrounding street curbs, street crowns, car tracks, or other points in the immediate vicinity that might be disturbed during the foundation construction. This disturbance or settlement may be expected through caving banks, yielding of street piling, borrowing of ground water, or running sand. Freedom against same can best be assured by tight sheeting, properly braced and carried well in advance at all times of the excavation. Having established the aforementioned benches, periodic reading on same will be taken and a careful record of the results preserved. Unless startling conditions manifest themselves through cracks in the walls or pavements, weekly readings will probably be sufficient until such time as foundations have reached grade level, after which they may be discontinued. If the new structure is to be annexed to an existing building, with communication thereto at one or more levels, the engineer will take check readings on all floors of the old buildings to detect any departure of same from the assumed levels. If the information is not otherwise available, it will be well at this time to cross-section the site as then found, for the purpose of checking excavation quantities later on.

5. Photographs.—An extremely valuable supplement to the engineer's records can be obtained through the medium of photographs taken of the site before building operations are

started. Such photographs should be identified by name, number, and date scratched on the negative or, better still, by a transparent label pasted thereon. A series of such photographs taken at weekly or 10-day intervals throughout the entire construction period form an extremely instructive and invaluable record of the operations. If possible, photographs should be taken from the same viewpoints so as better to illustrate the progress during succeeding intervals.

6. Removal of Pipes, Wires, etc.—Service pipes, hydrants, lamp posts, mail boxes, poles, and wires which encroach on the site should be noted, identified for ownership, and the owners notified to remove or properly protect same.

7. Wrecking.—Before wrecking existing buildings, suitable precaution should be taken for protecting the public traffic and pedestrians. The size and location of the operation will determine the method to be adopted. A tight fence, 6 ft. high, at the curb line, turning the sidewalk traffic onto a temporary walk laid in the gutter, may be sufficient. In more populated districts, and where the operation is to be of some length, it may be required to erect a shelter shed over the sidewalk, permitting the public to retain the use of the latter. Building ordinances of most municipalities cover this point, and they should be consulted to provide against possible violations. If sidewalk vaults are to be incorporated in the new building, the walk way can be elevated above the normal grade a sufficient distance to facilitate the passing of materials beneath and into the lot as excavation proceeds. By erecting the shelter in this manner, it can in many instances be retained to serve throughout the entire construction of the new building. The supporting sills will be carried on temporary wooden bents until retaining or street walls are up and permanent sidewalk beams are in place.

The wrecking of frame structures presents no features requiring special preparations. Brick, steel, and concrete, however, cannot be successfully handled without a well-studied program and more or less of an equipment plant, depending on the type of structure, ground area, and height. If more than three stories, brick and rubbish chutes will be found to be indispensable. Their erection should be such as to make easy delivery to wagons or trucks at the lower end. Except in cases of shallow buildings, the chutes should be located near the center of the building, thus equalizing the wheeling or handling on the working floor above. Temporary planked driveways may be provided for bringing the trucks or wagons to the bottom of the chutes.

7*a*. Disposal of Waste.—Driveways should be laid out so that traffic is continuous in one direction. To accomplish this, enlarged openings may have to be provided through external walls of the ground story, with consequent shoring, but the effort will be worthwhile, for speed on a wrecking operation is almost wholly dependent on ability to move the resulting material and rubbish away from the site promptly. Rubbish chutes are commonly built of 2 or 2½-in. plank, 30 to 36 in. square, erected vertically, in story lengths, with the splices directly above the successive floor lines. No bin is required, and control at outlet is secured through a floating false bottom, full area of the chute, attached to long wooden lever. Brick chutes are composed of open troughs 30 in. wide and with 12-in. sides set at an angle of 45 deg. but reversed through each story to provide a zigzag path in the usual method.

7*b*. General Equipment for Wrecking.—For lowering steel members, pipe, and other heavy pieces of equipment that may be encountered, a pole or light derrick may be found necessary on the working floor. Materials are lowered through a court way, if one is available, or, if not, a hatchway can be cleared through the various floor systems of sufficient size to pass the loads required. The acetylene torch will be found invaluable for dismembering the steel frame or for cutting down pipe lines, reinforcing rods, or any other metal obstructions which may be met with. For heavy brick walls and reinforced concrete structures, the skull-cracker, or heavy cast-iron ball, suspended over the part to be shattered by a derrick boom and released for a free fall by means of a trigger attachment or magnet has proved of good economy. A 2-ton weight and a drop of 10 or 12 ft. will break down all but the most obstinate resistance with a few blows.

Wrecking operations are quite generally handled by specialists in that line, as they are the better equipped for disposing of the old materials than would be the ordinary builder. When sublet, it is customary to require the wrecker to remove exterior walls to grade lines and interior walls and footings to basement floor line.

PILE DRIVING

By H. E. Pulver

8. Pile-driving Methods.—The most common method of driving piles is by steam power. Gasoline, kerosene, electric, and compressed-air engines are used to some extent. Compressed

air may be used instead of steam in some types of steam hammers, as the Arnott and McKiernan-Terry, for example. In some few instances, in out-of-way places, horsepower is still used to pull up the hammer. Hand tread mills or hand hoists may be used where labor is cheap. The last two methods are uneconomical and are seldom used when other power is available.

9. Driver Leads.—The leads support the pulleys used to raise the hammer or piles and serve as a guide for the hammer. They should be about 7 ft. higher, for the smaller hammer, to about 15 ft. higher, for the large steam hammer, than the length of the piles to be driven. The leads are usually two parallel upright members held in position by bracing in the form of a tower. The whole thing rests on a frame of horizontal members, which also carries the hoisting engine. Hanging leads are sometimes suspended from derricks or cranes and used in driving piles in deep trenches or excavations having a large amount of internal bracing. The leads may be steel, wood, or a combination of steel and wood. Leads are commonly made of wood and lined with iron to reduce friction and wear. Steel leads are more subject to deformation, caused by a pile striking the leads, than are those made of wood. Steel leads are also liable to shake loose at the joints. The leads may be tipped a little for driving piles with a small batter, or false leads may be used for driving piles with a large batter.

The leads, together with the bracing and engine, are placed on rollers or on a turntable which is placed on rollers. For water driving, the leads are mounted on a scow which is usually 18 to 20 × 60 ft., and 4 ft. deep. Pile drivers mounted on cars are often used for railroad work.

10. Steam Hammers.—There are two types of steam hammers, the single acting and the double acting.

The single-acting hammer is raised by steam and then falls by gravity. The force of the blow depends on the weight of the hammer and the distance through which it is dropped. The ram weighs from about 550 lb., for sheet piling, to 7500 lb. for heavy concrete piles. The heavy hammers are more frequently used for foundation work. The number of blows varies from 50 to 60 per minute depending on the steam pressure.

In the double-acting hammer the steam raises the hammer and assists gravity on the down stroke. The hammer strikes from 100 to 120 blows per minute. The weight of the ram is from 21 to 1250 lb.

11. Drop Hammers.—Drop hammers are raised in the leads by means of a hoisting rope or steel cable and allowed to fall with the force of gravity. The weight of the hammer varies from about 500 lb. for short piles and sheet piling to 4000 lb. for large piles. The weight necessary depends on the length of the piles and the character of the soil. Most contractors have several different weights to select from. Hollow hammers are sometimes used, and the desired weight is obtained by loading with pig iron or junk.

12. Jetting.—The use of jets is advantageous when piles are to be driven in sand, gravel, or soft-packed clay. The jet water, under pressure, loosens the material and carries it to the surface. The water also lubricates the surface of the pile.

Two jets should be used if possible. When a single jet is used, it should be first used on one side and then on the other to keep the pile going straight. The jet pipes should not be fastened to the pile but kept moving up and down to extend the lubricated areas from below the point up to the ground and to keep inflowing soil clear of the sides of the pile. The jet is used in connection with some form of pile driver. Very little driving is necessary unless some hard material is encountered.

The jet pipes should be 2½ to 3 in. double-strength pipe, with a ⅞-in. or 1-in. nozzle. All bends should be of long sweep in order to diminish pipe friction losses of pressure. The jet hose should be for 250-lb. pressure and be clamped onto long nipples with three clamps on either side of the joint. The form of nozzle is of importance and should be adapted to the materials to be penetrated.

The pump and boiler capacity must be large enough to deliver the water at 175-lb. pressure for ordinary materials and about 250-lb. pressure for hard-packed material. A vertical pressure balancing tank between pump and jet pipe is of material assistance in heavy jetting.

The use of a single jet is often effective in sand or fine gravel, if it is first run down full depth where the pile is to be driven; and upon pulling out the jet, if then placed immediately,

the pile can often be driven full depth without further jetting. Care should be taken in placing jetted piles not to overjet the hole, so that sufficient resistance is encountered by the pile to develop its full bearing power.

Jetting is particularly applicable to driving in packed sand and gravel. Sand and gravel offer a high resistance to a pile when driven with a hammer alone, often injuring the pile.

13. Protection of Pile.—When piles are of good hard timber and are axed to a square point, they will drive in all but the hardest material or boulders, without metal points. But in very hard clay and coarse gravel with boulders, steel or cast-iron points are necessary to prevent brooming and to cut the way for the pile. The usual type of strap point is of very little use. as the pile will spread out around it in driving and often broom worse than when unprotected, The best form of point is a recessed circular cast-iron cone, with a rod cast in it to be driven into a slightly smaller hole cored into the tip end of the pile. This cast point, if made in the shape of a triangular pyramid, will cut its way into much harder materials than will the conical or any other common form of point.

Wooden piles may be kept from brooming at the top during driving by a bonnet casting or else be ringed with iron rings of about $\frac{7}{8} \times 2\frac{1}{2}$-in. size. Steam hammers may have a recessed base to go over the top of the pile, but for drop hammer a similar bonnet of cast steel to run in the leads can be provided.

Overdriving of the piles should be guarded against, as it causes the piles to shatter beneath the ground. Such a pile is almost useless. When the hammer bounces or the pile kicks back it is an indication that the latter has struck something it is unable to penetrate.

14. Followers.—A follower is used when a pile is to be driven below the leads or below the ground or water surface. It is a short pile or a cylindrical casting of some type placed on the pile to transmit the force of the blow from the driver to the pile. The follower is held to the top of the pile by means of a recessed base or a band of iron and either fits in the base of the steam hammer or is provided with a cast bonnet to hold it in the leads.

15. Driving Concrete Piles.—Concrete piles, after careful curing, should stand more punishment in driving than wooden piles, but the top of the pile must be protected against shattering by a special cushion cap. This cap may consist of a steel casting having a top recess to receive an oak or hardwood follower block; and a bottom recess to be packed with old hose and rope and lastly with oak blocks to come in contact with the concrete. When the rope or blocks become burned, through heat of driving or crushed solid, they must be renewed.

A hole through the center of a concrete pile, as provision for jetting, is not so effective as jets used outside the pile. Where the material into which the piles are being driven is very firm or packed, jets should be used and as much shock on the pile eliminated as is possible.

16. Splicing of Piles.—Splicing of piles is necessary when exceptionally long piles have to be used or when there is a lack of headroom for driving. The piles may be spliced by placing a metal sleeve over the joint or by fishplates bolted on the four sides of the pile. Lap joints are not satisfactory.

17. Cutting Off Piles.—When wooden piles have been driven with a follower cap, they are seldom broomed up and, therefore, do not require cutting off to give a solid bearing on their tops. But when broomed up from ordinary driving they must be cut off square to solid timber, or if they are not driven down to proper level they must be cut off to proper height. This can be done in the dry by ordinary two-man cross-cut saws, but when the cut-off is under water, they must be cut off by a diver or else by a circular saw working on a vertical shaft in the pile-driver leads.

Wooden piles are usually cut off below ground-water level or below low water when the piles are driven in water and are capped with concrete. Alternate wetting and drying of the pile causes it to decay rapidly.

Frequently, there are cases where old piles require removal by cutting them off, and this can be done by a diver or else by placing dynamite around them and firing it by a battery.

18. Pulling Piles.—Steel sheet piles can easily be pulled with special pulling nippers into which the pile line is hooked. Holes may also be bored through the web of the piles at the top,

and a shackle bolted on. Reversing a double-acting steam hammer to strike upward, supporting the whole from a derrick, is also done successfully.

Wooden sheet piles or round piles are pulled by taking several turns around the top of a pile with a heavy chain, or with a wire-rope sling, and hooking a set of double or triple wire-rope blocks into it. It may be necessary to keep hold of a pile for some time to overcome suction before it starts, but if it does not start readily, a blow or two from the pile hammer may loosen it. Jetting around piles is also of assistance in loosening them as they are being pulled upon.

The use of levers and jacks for pulling piles in soft material is often effective; but for any large number, a power rig should be used.

EXCAVATING

By A. G. Moulton

Excavating, with the attendant grading, is necessary in every building enterprise. Generally being the first branch of the work undertaken, it is often unconsciously called upon to bear many of the organization expenses that might be more correctly prorated against the succeeding trades. For that reason, a carefully studied program should be mapped out before starting work to be sure that proper methods are chosen and all economies observed.

19. Equipment for Excavating.—Local conditions vary so with each building operation that anything more than a brief description or reference to the proved methods and various types of equipment for excavating purposes would be useless in an article of this kind.

In the case of excavation for solid foundation walls and piers, where the work would be mainly pick and shovel, and the excavated material disposed of by wasting on the banks or transferred by wheelbarrows in the immediate vicinity; or in the case of basement excavation where the ground may be broken up by a plow and removed beyond the building lines by two horse scrapers or slips or directly loaded into wagons or trucks which have been driven into the excavated area; or even in the case of the larger excavations where the steam shovel becomes a possibility, there is not much danger of a mistake in choice as to method. It is in the deep basement work through varying conditions of soil that the opportunity for careful study of plant layout is encountered.

20. Steam-shovel Excavating.—Where 1500 yd. or more are involved, and where the width of the lot will permit a full swing, it is generally conceded that, except in rock work, the small revolving steam shovel running on tractor equipment provides the most economical tool. On the first cut through, the wagons or trucks are loaded while standing on the grade. When the depth of the cut exceeds the limit of the shovel, it becomes necessary to introduce the bridge or inclined driveway to bring the trucks down to the floor of the cut. A booster engine set on the grade level to pull or ease the loads out will permit of a sharper incline.

When the depth of cut reaches a point that will prohibit the further use of an incline, other features will have been introduced in the way of holding or shoring of banks with consequent restriction on working area such as to render unprofitable the further use of the shovel. If the basement is to go to still further depth, then hand work will be resorted to and the excavated materials carried to above street level and deposited in chutes or hoppers for easy transfer to trucks at that point. The elevation may be obtained either through small cars and barrows on platform hoists or in buckets operated by boom derricks. On such work, the use of the clamshell will not be practical, as the cross-lot bracing for supporting street banks would cause too much interference.

21. Shoring, Sheeting, and Underpinning.—The holding or shoring of street banks and underpinning of adjoining structures often presents quite serious complications especially if the excavation is to be carried to some depth through treacherous soil. In such instances, the expedient is sometimes adopted of sinking a trench full depth, on the line or curb wall, in advance of the general excavation. This trench may be opened in sections if the entire frontage involved would be too great to handle safely in one operation. The trench will be sheeted tight or not, depending upon the character of the soil, and cross braced with struts and wedges. On heavy work, screws are introduced to make up for ground movement and settlement. Up to 15 ft.

in depth, the material from such a trench may be benched out by hand. Beyond that depth, the excavated material should be passed up by mechanical means, such as buckets operated by hand winches or boom derricks. The trench having been completed, the wall is next constructed, and upon acquiring normal strength the general excavation of the basement proceeds. Temporary supports to help resist the earth pressure must be given the wall from the inside as the ground is removed. This is generally obtained through batter braces, which are left in place until the building columns and permanent framing have been installed.

21a. Sheet Piling and Shifting Soils.—Where ground conditions are good, such as in clay, or compact sand and gravel, the above method with its great amount of hand work would be too expensive. In such cases, the general excavation would be carried down the full area of the lot, and the banks left at sufficient slope to stand alone, or skeleton braced from the inside. In dry sand and running soil, a tight sheet piling will be required. This may be composed of vertical planks, square edged or matched as the case may require and driven through by hand or by small sheet hammers operating on steam or compressed air. When water is to be encountered, a system of steel interlocking sheet piling will possibly be chosen.

Any type of sheet piling will require bracing to hold it in position, and the proper erection of this bracing, so as to permit the later carrying up of permanent walls, should receive due consideration. Instead of building them in, leaving a hole to be plugged later, it is generally preferable to strike the braces as the work goes up, replacing same on the inside of the wall.

21b. Protection of Adjacent Structures.—The holding and shoring of adjoining buildings generally presents so many elements of risk, that, unless it is a relatively simple operation, this branch of the work had better be entrusted to specialists in that line.

Underpinning where the soil is unyielding can be carried out successfully and without great danger if due precaution is given to the number and length of the different sections which are to be worked on simultaneously. These should not be too close together and generally not in lengths over 6 or 8 ft., and the load of the structure should be brought to bear on the new work before opening up an adjoining section. This is accomplished by means of slim metal wedges inserted between specially prepared stone wedging blocks built into the underpinning and driven home after the masonry has taken a set. If the soil is particularly unyielding, the same results can be obtained by a wedge course of brick inserted by the mason as he tops off the underpinning work. When using the sectional method, little or no timbering will be required beyond an occasional spur brace to overcome tendency of the old wall to slip. If the old wall is in poor condition, or the soil under it inclined to be treacherous, needling of the wall had better be resorted to and the aid of a specialist secured.

22. Rock Excavation.– Rock excavation is carried on by the aid of explosives, and in most communities not only is a licensed powder man required to do the shooting, but regulations are also provided covering the manner in which the dynamite may be handled and stored. On small work, hand drills are successfully used, but where the yardage to be removed is great, steam or air drills should be provided. The use of the explosive is to lift the rock slightly and break it up into sizes convenient for disposal. The number and size of the respective charges is dependent upon the surrounding conditions, and the supervision of this class of work should be entrusted only to those who are thoroughly familiar with its possibilities. After being shattered, the rock is loaded in skips or buckets and removed from the basement by a boom derrick or picked up by a steam shovel and deposited into trucks or cars.

23. Open Caissons.—Caisson excavation may be carried on in the open or by means of locks and compressed air, the latter expedient being adopted only when excessive water conditions preclude the open method.

For building footings, caissons are generally designed circular in form, varying from 4 to 10 ft. in diameter and carried down either to bed rock, or stopped off and belled out on some convenient strata of hardpan. Under the former condition, depths of 100 ft. and upward are sometimes encountered. Excavation is done by hand or air spades, the excavated material being lifted to the surface by buckets suspended over the mouth of the well and raised and lowered through the agency of a niggerhead, the mechanism receiving its power through a traction cable lead from a conveniently placed hoisting engine. Ten to fourteen wells comprise a setup and are commonly run from one engine. This provides a constant speed for all the niggerheads, and the individual operator at the head of each well on signal from below raises the filled bucket by taking two or three wraps of the hoisting line over the niggerhead. Another method growing

in favor is the use of individual niggerhead hoists with self-contained electric motor. They are recognized as being safer in operation than the multiple-hoist arrangement and permit of greater elasticity of setups. Where electric power is available they are to be preferred. The excavation is carried down to a depth of 5 ft. 4 in. and then lagged with 2- or 3-in. matched lumber, the lagging being held in place by metal rings inserted two to each length of lagging. The rings are rolled out of flat bars and made up in two sections to the ring. After being brought to position, the two halves are bolted together at the ends and wedged tightly against the lagging. The excavation then proceeds for another stretch and repeats until the bottom has been reached.

For open caisson digging in medium-soft ground and where boulders are not to be encountered, there is now available a power-driven mechanism with cutter head adjustable for varying diameters of wells that is lowered on vertical shaft into position over a caisson, in which has been inserted a length of cylindrical steel lagging. The cutter head loosens up the ground as it sinks into the earth permitting the steel lagging to follow along. Water if not normally present is introduced, and the cutter head removed. A bucket with bottom built on the plan of the old flapper foot valve is then lowered and raised until the saturated soil within the lagging has been removed and the process of cutting is again resumed, new lengths of lagging being added at the top. Machines such as these, also others which are developed on the principle of the trenching machine, are often useful, particularly where labor is apt to be expensive or scarce.

When working through wet ground, bailing may not be sufficient and pumps may be required. For this purpose, steam syphons or pulsometer pumps will be found most convenient. Sections of steel lagging may be required if the ground is very soft, but its use is not always attended with satisfaction. Continued pumping of a well with little or no headway shown is bad practice, and will lead to sure trouble on adjacent wells. When such conditions arise, pumping should be discontinued and every effort first exhausted to stop the inflow of water and sand by tightening up the lagging. An inner set of sufficient length driven ahead of the excavation may make it possible to pass the soft spot. This procedure, however, is at the expense of a reduced area on the caisson, and for that reason may not be permissible. The use of hay or straw for packing back of the wooden lagging will often overcome water difficulties which otherwise seem insurmountable.

Electric lights and, in some cases, forced ventilation will be required for the workmen at the bottom of the wells.

When wells are belled out, it is not customary to lag the last section but to immediately fill it with concrete as soon as it has been shaped up and cleaned out.

The rings may be salvaged as the concreting is brought up, but the lagging is left in place.

24. Compressed-air Caissons.—In ground conditions where water or quicksand would make open work impractical, compressed air is resorted to. In this work caissons are carried down in the open as far as possible and then an air-lock is installed at the head of the well. Through this vestibule, which by the manipulation of valves is alternately under normal and then at an increased air pressure which varies with the requirements, all workmen and excavated material must pass. The air pressure in the working chamber is kept at a point just sufficient to exclude the incoming water and, to a workman accustomed to it, little or no inconvenience will result.

Experienced men only should be used on this class of work, and every precaution should be taken to see that the compressor plant and all other apparatus is in first-class working order. The use of naked lights should be prohibited, as combustion will be found much more rapid than when exposed under normal pressure.

In the majority of cases, it will be found desirable to start caisson work from the normal ground level rather than to await the completion of basement excavation. The additional expense of hand over steam shovel labor for the yardage included in the caisson tops, will be more than compensated for by the saving in time to the building schedule and also the greater convenience in removing the caisson dirt from the premises.

FOUNDATION WORK

By A. G. Moulton

The term foundation work is generally considered to cover the construction of all supporting masonry including embedded steel up to that level known as grade. It may comprise curb and area walls, retaining walls, isolated column footings, foundation girders, wall footings, elevator pits, machine foundations, etc. The difficulties attending upon foundation work will be found to increase almost directly proportionate with its depth.

In present day practice, concrete is almost universally used for foundations. On smaller buildings such use may be restricted to footings only, with the retaining or foundation walls themselves run up in brick or hollow tile, but on larger work, where greater strength is required to resist earth pressure, concrete, either plain or reinforced, will be the probable choice. The general excavation or grading having been completed and footing trenches and piers opened up, concreting of same should immediately follow. If the soil will stand unsupported, forms are not necessarily required for a footing course, and the excavation should be made to neat lines.

25. Pumping of Excavations.—On all foundation work, pumping equipment of some kind should be provided so that trenches and pits can be pumped out before concreting is undertaken. The size and scope of the undertaking will determine the capacity and number of pumps required. These may be anything from the small hand operated diaphragm pump up to the larger capacity centrifugal and triplex types electrically or steam driven. The diaphragm pump, mounted on skids or trucks and gasoline driven, will find its use on any foundation job. For the deeper pits, the steam syphon or the pulsometer type of pump will probably give the best results. A liberal boiler capacity should be provided, however, if they are chosen. If the lift to the sewer or surface is so great as to require pressure pumps, it will be found desirable to first gather the ground water in a sump pit or temporary basin by means of diaphragm pumps, so that the sand and grit may settle out before being lifted.

It should be remembered that in open basements, particularly in clay where the surface water does not readily soak away, a 3-in. rain fall may tie up the entire operation for 48 hr. or longer. Under such conditions, a pumping plant of adequate capacity is always a good investment.

26. Damage to Excavations by Rainfall and Surface Water.—Proper protection should be afforded against damage from surface water flowing into the excavation from neighboring streets. At the height of a heavy rain storm, with the sewers taxed to their capacity, this may become a serious menace to the work, particularly if the street banks are sheet piled and the surface water finds entrance behind the sheeting. A small earth or sand dam thrown up on the street beforehand, parallel to the work, may prevent this damage.

Precaution should be taken to see that old sewer stubs entering the site are solidly blocked up to resist a back flow, and that all street sewers and water mains that have been exposed are substantially shored or braced.

27. Concreting Plant.—In choosing the proper type of concreting plant for any particular job, so many factors must enter into consideration that nothing but the most general suggestions would be of value here. Ordinarily, that type which is the most conservative on hand labor should be the adopted one. Mechanical concrete mixers are now obtainable in so many sizes and types that one will be found to meet any given condition of foundation work. As a result, hand mixed concrete is now seldom to be considered.

For street and curb walls, the small two and one bag mixers that can be readily moved from place to place and the charge spouted direct into the forms, will probably be found the most economical unit. For column footings, where the individual yardage is not sufficient to warrant the progressive movement of the mixer, the ½- or ¾-yd. mixers and concrete buggies will provide the solution.

For caisson work, where the yardage in each pier is considerable, a permanently established mixer serving through 1-yd. tilting cars on a narrow gage track, will give good satisfaction. Upon being dumped, the cars deliver their load into a portable receiving hopper suspended at the top of the well, and from there to the bottom through a flexible telescopic spout. This spout, approximately 10 in. in diameter, of light iron, is made up in sectional lengths of about 4 ft. each, the sections being removed from the bottom as the concrete rises in the well.

The use of a tower with gravity chutes for light foundation work will not as a general rule work out economically. If on the other hand, however, the character of the superstructure indicates the gravity system as being proper, its early installation and use on the foundations would be permissible.

Generally speaking, when in doubt as to the capacity of the mixer required, select the smaller size. This leaves you in a position where with a steady run-off before you, you can speed up the number of batches to readily obtain the desired output, whereas with an interrupted flow, the idle forces back of the mixer will be at a minimum. With the larger mixer under such conditions all lost or idle time is correspondingly felt on the payroll.

Availability of storage space and convenience of delivery for the dry materials are important determining factors in the selection and location of the plant. It should be remembered that the opportunities are infinitely greater for wasting labor back of a mixer than in front of it.

In some localities there are commercial mixing plants which will furnish ready-mixed concrete according to any specification.

28. Forms and Reinforcement for Foundations.—Form work and the placing of reinforcement for foundation work does not, as a rule, present the problems that are present in superstructure work. Piers and footing courses require only the simplest knowledge of form building, and the wall forms are the only ones that may call for a show in skillful design. The general subject of forms, their design and construction, is considered in Art. 39.

29. Waterproofing of Foundations and Basements.[1]—Waterproofing of basements is so intimately connected with foundation work that it is well to consider it at this point.

Various methods of waterproofing are in use, any one of which may be encountered by the builder. There is the integral compound, either powder or liquid in form, which is introduced in the concrete at the time of mixing, and directions for the use of which are furnished by the manufacturer. Another method is the coating of the finished wall with special preparations, such as ironite or the hydrolithic compounds. These are usually applied to the interior face of the wall, permitting the work to be done at any convenient time. A third method is the coating of the exterior of the wall with coal tar pitch, or, preferably, asphalt, in which are embedded two or more plies of roofing felt. Before applying any coating, the concrete surface must be clean and dry.

When conditions require a so-called pressure basement, a connecting strip of felt and asphalt is carried through all exterior walls as well as over all column footings at a level a few inches below the finished basement floor. After the walls are finished, the coating on the back of the walls is applied and connected to a lap provided on these horizontal strips and eventually it is also connected up to a sheet which extends under the entire basement floor. For basements which are under a constant head of water, this is one of the most successful methods, and if carried out with due care will provide ample and lasting protection. Particular care should be given that sufficient insulation is provided over the membrane where same extends beneath boiler settings. With the increasing use of oil burners and the extreme heat which they generate, special precaution only will preserve the waterproofing from destruction in such places. When it is impractical to provide sufficient space in which to apply the exterior coating on walls after they are in place, the felt and asphalt may be mopped on to a 4-in. brick or tile wall, which is run up in advance and against which the permanent wall is then installed. If this be of concrete construction, then the vertical felt course as well as all horizontal ones should be protected against damage by a safety course of cement mortar trowelled on.

Pressure should be relieved until the last through some conveniently located sump pit at which time this place may be sealed; and if the waterproofing is skillfully applied the basement will be tight thereafter.

STRUCTURAL STEEL WORK

By A. G. Moulton

Structural steel is utilized so frequently in the various phases of building construction that a general knowledge of its proper and economical handling is most essential. Aside from its use as sheet piling, and in superstructure work, steel is used to some extent in building operations as grillage beams and foundation girders which support the column bases or stools, which, in turn, carry the columns. In some designs the cast stools will be eliminated and rolled or cast steel billets substituted.

30. Setting Grillages.—Grillage is commonly used as two sets of steel beams on each footing—one placed on top of the other, but reversed as to direction of length. The individual beams making up a set of grillage are tied together by means of bolts and pipe supporters, and wherever the assembled unit is not beyond the capacity of the field forces to handle, it will be found desirable to have the assembling done at the mill.

The concrete of footings or piers where it receives the grillage should be left by the mason 2 or 3 in. below the final level so as to enable the more accurate setting of screeds. Should there be a division of responsibility between the mason and the steel erectors, the best results will be obtained by having the mason set the screeds. These should be brought to exact level by engineers' instruments and solidly grouted into place. Pieces of 1½-in. angle back up, or wooden strips about 1 × 1½ in., make satisfactory screeds. Grillage beams are adjusted for position laterally by means of lines stretched through, on column center points and projected down by the aid of small plumb bobs If an engineer's transit is available, more exact work will be obtainable. An accurate set of grillage beams, which means the same for stools and columns, is well worth the effort to obtain. A tolerance of ⅛ in., plus and minus, both in level and line is unsatisfactory practice.

[1] For a more complete treatment, see Hool and Johnson's "Concrete Engineers' Handbook."

As soon as beams have been set and checked by the engineer, they should be concreted in to guard against accidental shifting. On the top set, hand-hold clearance should be left to insert column bolts, if same are required.

31. Equipment for Erecting Steel Frame Buildings.—On steel frame buildings, the erection equipment will be delivered and set up while the foundation work is being carried on. The selection as to type of derrick is governed by the size of the building site and the character of the work to be handled. If it is such as to give proper play to the revolving boom, then either a guy derrick, stiff leg, or the so-called Chicago boom, may be used. Where proper guying can be obtained and on lots 40 ft. or more in width, the guy derrick will prove the most economical. Where suitable anchorage is difficult to find, or where the guys themselves would be objectionable, as on narrow corner lots, the stiff leg derrick will probably be chosen. On narrow lots, with neighboring building on one or both sides, of height equal or greater than the new building, then the Chicago boom may be used. This presupposes that the consent of the adjoining owner for such use of his structure can be obtained. The expedient of setting the derrick on top of the adjoining building should be adopted only as a last resort. Greater initial cost, the discomfort of tenants through vibration and confusion of workmen going to and from the roof, the expense of keeping roof in water-tight condition during operation, and the permanent repairs later, will all go to more than offset any saving gained through not having to make additional moves in carrying the derrick up with the new work.

32. Locating Derricks for Erection.—Having chosen the type and number of derricks required, the exact location of mast centers should be duly determined. This should be such as will allow the greatest range of action over the building area, suitable consideration being given to the point from which loads of steel will be received, and sufficient length of boom reserved for that purpose.

33. Cycle of Erecting Operations with Derricks.—With the guy derrick, full revolution of the boom, or 360 deg., is possible; with the stiff leg but 270 deg. can be reached with full swing; and with the Chicago boom but 180 deg. The greater range of the guy derrick makes it much to be preferred. For building work, booms from 75 to 90 ft. in length are used. A guy derrick with an 85-ft. boom will develop the greatest efficiency when serving an area of approximately 10,000 sq. ft. The tonnage involved in such area, will generally work out so as to provide a 4-day cycle between raises. When two or more derricks are engaged on the same operation, precision of raises must be observed otherwise, confusion will result in the shipping, hauling, and unloading of steel at the building site. The expense of an idle derrick with full crew waiting for steel is such that any departure from the estimated schedule is promptly disclosed through the daily cost statements.

On a 4-day cycle, one day will be required in receiving the steel and elevating it to the working floor. Such columns as will not obstruct the play of the boom will be set between loads. The second day will be used in sorting out the various beams and girders and throwing them out on the working floor in the various panels to which they belong. When sorting steel, the boom should never swing without a load, and the active foreman will so arrange his work. Sorting hooks are used for handling individual beams and, as soon as a number of beams for the same panel have been found, a sling is thrown around them and they are delivered to the proper location. The third day, the erection of the two tiers above the working floor is made, and on the fourth day the derrick is closed in and raised to the new level, and planking laid for the next working floor.

When working on shops, factory buildings, and other low structures where the tonnage is mainly in crane girders and roof trusses, one or more poles working abreast and moved back out of the way of the advancing work, will be the method chosen. On such class of work, if the tonnage is sufficient and direct, and railroad connection is convenient, the locomotive crane will be found more economical than the poles. On heavier and higher structures, such as train sheds, power houses, etc., which exceed the working range of either poles or locomotive cranes, resort is then had to the traveler, with one or two booms mounted on same, as conditions may require.

34. Choice of Power for Derricks.—Wherever electric power is available, it is generally to be preferred over steam for the derrick hoists, particularly on high buildings, where to overcome the excessive drum size required to hold the necessary length of cable otherwise required, the hoists are themselves raised to levels midway in the building. Greater cleanliness, the avoidance of the coal and ash problem, to say nothing of the time saved in not having to raise steam, are all in favor of the electric equipment.

35. Bolting and Plumbing of Superstructure.—As steel work is erected, it is loosely bolted by the connectors, except in those panels which carry the load of the derrick. These sections

should be bolted up 100%, and all tie-rods, if any, inserted and drawn to place before the derricks are raised. Before riveting is started, certain plumbing of columns may be required. Generally, this will be found in connection with the corners of the building and those columns adjacent to the elevator shafts. The great refinement which has entered into both shop detailing and fabrication of steel work during recent years, has made unnecessary, to a large extent, the plumbing heretofore required. Where plumbing is needed, it is accomplished by means of diagonal cables strung in a vertical plane and tightened by means of turn-buckles or steamboat ratchets. As soon as the work is riveted, the plumbing guys can be removed.

36. Riveting.—With good average workmanship on the part of the fabricating shop, it is possible to start driving on the floor panels as soon as the beams have been raised to position and by keeping one or more riveting gangs engaged above the working floor, or that where the derrick sets, they will have the top tier driven before the deck planking is raised to become the new working floor. The riveters then drop back and catch the intermediate tier, returning again on the third day to the new upper level and the cycle is repeated. This method is extremely valuable as a time saver, inasmuch as it permits the centering for the floor system to keep directly behind the derricks.

37. Steelwork the Pacemaker.—Steelwork being one of the principal lines of work, should be made the pacemaker for the balance of the trades; therefore, it is doubly essential that a good, clean job, with all points caught up as it goes, should be given. With such an example, other trades are more apt to accept the invitation and follow along similar lines. On the other hand, if the job is not cleaned up as it goes, and the riveting or painting is allowed to drag, then the effect will be immediate, the following trades will be strung out to unnecessary limits, and the progress of the whole building will suffer delay.

FLOOR CONSTRUCTION

By A. G. Moulton

Uniformly progressive installation of the various floor systems in a building, whatever may be their type, is a healthful indication of the progress of the structure as a whole. The more even the rate at which floors are installed, and in steel frame buildings, the more closely their construction is kept up with that of the supporting steel or walls, the better will be that building's progress. This, perhaps, will be more readily understood when it is considered that on buildings of more than the one floor level each succeeding floor system as installed furnishes just that needed additional space on which to advance the trades in sequence, and provides an opening for the next and newest trade on the lower level.

Ordinarily, the normal progress of trades up to the point of plastering is through the building from the bottom up. From that point on, in fireproof building of 8 stories and under, other conditions enter into consideration and it may be found advisable to start the finishing trades from the top and work downward. On buildings above 8 stories in height, where a normal schedule has been maintained, this change in direction can be made only at the expense of definite delay in the final completion of the building.

In view of the importance of the rate at which floors are constructed, it can be seen that every effort should be made to schedule the delivery of materials so that the floor installations may proceed uninterrupted at the predetermined pace.

38. Centering for Floors.—In all cases some type of centering or forms will be required, the selection and design of which are usually left to the discretion of the builder. Having reached a decision as to the type, consideration is then given as to the quantity of centering which should be provided in order to give uninterrupted service. Reference to the building schedule indicates the allotted time from finish to finish of the respective floor systems, while the type of system and the season of year in which the construction is proceeding determines the length of time that should elapse between the placing and stripping of a set of forms or centers. With these two factors known, the extent of centering required will easily be determined.

On steel frame buildings with short or semi-long span arch construction, the centering can be hung from above with considerable advantage, inasmuch as it leaves the story below unobstructed by shores or props. For the long-span arch the support from below provides the more feasible method.

39. Forms for Concrete.[1]—In the design of forms, centers, and other false work, careful consideration should be given to the probable methods of removal—that is, the design should be such that the forms can be taken down with a minimum of effort and with the least possible damage to the parts involved. This will be better realized when it is understood that over half the expense of concrete construction is made up in form costs plus the labor of removal. As a consequence, any labor economy of this nature that can be incorporated in the design will be found to multiply itself throughout the building, since the forms, through easy handling, are capable of being re-used. If satisfactory results are to be obtained, careful attention should be given to the kind and type of lumber to be employed, to the arrangement of joints at internal angles where one section abuts another, to the adjustment of supports and props so as to permit of early and partial stripping, to the application of form oil or other coating to the inside of forms before using, to the cure of that ever prevalent abuse of unnecessary nailing, and to the limited use of camber in girder and beam forms. On buildings of multiple stories, where forms are used on an average of three or four times, it can be safely assumed that, if the above precautions are taken to make possible such re-use, then all the initial requirements as to stability and tightness will likewise have been covered.

The knowledge and experience of the builder will generally enable him to select proper sizes of lumber and supports without resort to special calculations. If in doubt, however, reference can be had to the many tables which have been prepared on the subject, and which are available for all conditions usually to be met with. Methods by which the concrete will be transferred to the forms should be considered, and sufficient bracing be provided to compensate for undue loads from that source. Horizontal members should be able to support the weight of concrete and the construction load. Vertical members must resist a hydrostatic pressure of about 145 lb. for each vertical foot of height.

On all types of concrete arches between steel beams, it is highly desirable to keep the runway plank and workmen off the centers or panels as much as possible. The location of runway plank should be determined in advance, and proper supports provided that will not interfere with reinforcement and other items entering into the construction.

On all operations of importance—and it is hard to conceive any items of structural concrete which would not classify as such—a careful and well organized system of inspection should be provided that shall remain in force from the time the forms are started until their final removal from the building. Such service is a necessary part of the contractor's organization, even though supplemented by the owner or designing engineer. Individual inspectors should be carefully instructed as to their respective duties, and a comprehensive system of daily reports installed to insure their adherence thereto.

The quality of dry materials, the method of storage, the handling and proportioning of the materials, the erection and thorough cleaning of forms before filling, the operation of pouring, the watching against possible settlements or distortions of forms during that period, the care of concrete surfaces while undergoing the setting process, as well as the proper length of time to intervene before stripping, are all matters of too vital importance to impose upon the unsupported judgment of the construction foreman. He, as a rule, is too engrossed with the question of speed and initial cost to make possible an appraisal of such items at their true value.

39a. Lumber Forms.—Spruce and pine, either Norway or Southern, are the lumbers most generally used for form work, partially seasoned wood being the best. Hemlock is not desirable for forms owing to its inability to weather while standing exposed. For all surfaces where the concrete is to be later exposed, dressed lumber should be used. For flat surfaces, such as wall or floor panels, shiplap is preferable, although tongue-and-groove is satisfactory, and even square edge may be used if precaution is taken to provide sufficient supporting members to prevent buckling of the individual boards. For columns and girder bottoms, 2-in. stock, and for floor panels and beam and girders sides, 1-in. stock may be used; while footings may take either 1-in. or 2-in. stock, depending upon local conditions. The use of uprights of 3 × 4 in. or 4 × 4 in., spaced from 3 to 6 ft. apart, is the usual practice.

39b. Finish of Forms.—All interior surfaces of forms should be dressed true to give good surfaces to the casting, free from joint and other marks. On exposed work, all sharp corners should be bevelled by inserting small triangular strips in the forms. After forms have been erected, ice and snow should not be allowed to collect therein, and, if so,

[1] For a complete treatment of "Forms" including their design, see Hool and Johnson's "Concrete Engineers' Handbook," pp. 93 to 137.

such accumulations should be removed before concrete is deposited. If forms are allowed to stand for any considerable period before filling, shrinkage cracks will have to be taken up and all supporting timbers and braces gone over and tightened bfore pouring is resumed.

To give specially smooth surfaces and to prevent the production of grain in the concrete surface, as well as to permit easy removal of forms, the interior surfaces may be coated with soft soap, or with form oil, which is crude, or other heavy mineral oil.

39c. Removal of Forms.—The elapsed time within which forms may be removed with safety, is not entirely a matter of individual judgment. The normal process through which setting concrete passes is such that, with the standard proportions and mixes now universally used, a minimum period is definitely established, below which the forms can not be disturbed without permanent impairment of the work. This minimum, under most favorable weather conditions, can be assumed at 5 days for vertical compression members, such as columns and walls, and from 7 to 10 days for such other members as are subject to bending stresses. From this up to the maximum period, the elapsed time should increase in widening ratio, depending upon the departure from normal of the three following factors: (1) the consistency of the original mix; (2) the temperature encountered in the first 7 days; and (3) the atmospheric conditions in the same period, with particular reference as to its humidity. Short of freezing weather, the maximum period should not exceed 21 days.

Before striking any set of centers, inspection of the work should be made, and its soundness determined by tapping with some heavy object, the resultant ring indicating the degree of hardness then obtaining. Care should be taken not to mistake frozen concrete for that which has set; and for this purpose the system of daily reports heretofore mentioned should be referred to.

The successful removal of forms is an operation requiring considerable skill, and unless carefully watched will undoubtedly be responsible for many unsuspected drains upon the payroll, to say nothing of the lumber pile. The foreman or superintendent who will personally supervise the striking of a set of difficult forms will never thereafter be caught with a poor design, or permit careless and faulty work in the erection.

Forms for circular columns and for flaring column heads, are quite generally of steel. Steel forms for floor and wall forms are also coming into extended use. They are made sectionally and in extensionable units to provide easy handling and adaptability to varying constructions. Steel forms give a full, smooth finish to the concrete surface, and have a high salvage value.

40. Bending and Placing Reinforcement.[1]—Steel should be checked, assorted, and stored as soon as it is delivered at the site. It should be blocked up free from the ground, and should be stored in such a manner that those rods needed first may be easily reached.

In localities where trade custom permits, the bending of reinforcement can quite often be done more economically at the mill than at the building site. Where this is not the case, suitable equipment, in the way of bending machines, many varieties of which are now on the market, should be provided, and will be found a good investment, particularly if the tonnage is heavy and the bends are complicated. For light tonnage and simple bends, a very satisfactory makeshift can be devised on a home-made bench with the aid of dowels or pins adjustable in position to suit the varying templates, and a piece of pipe to act as lever in applying the necessary bending force.

All ordinary bending is done cold. Only when working in sizes 1¼ in. and over will heat be required, and then only to a low degree. The bending force should be applied gradually, as a jerk is liable to snap or break the bars, particularly in the high grade and rerolled steels.

It will be found advisable to so arrange that all rods of the same size and shape are bent at one time, so as to avoid the resetting of templates.

In the placing of reinforcement, the importance of a thorough supervision and inspection cannot be too greatly enlarged upon. Whether it be in the shape of rods, spirals, stirrups, fabric, or lath, the accurate placement and adjustment to position, so that it may not be displaced during subsequent operations, are details deserving of the closest attention. Not only is the safety of the work involved, but through the application of systematic principles, improved costs will likewise be found to result. For the proper spacing and support of reinforcement in the forms, many ingenious devices, such as chairs, clips, and spacers have been perfected and their use can often be recommended.

Steel should be thoroughly cleaned before being placed in the forms, in order to obtain a positive adhesion of the concrete to the steel. A slight film of rod rust is not objectionable, but no rod should be set in place on which rust scales have formed.

[1] See also Sect. 6, Art. 13; for more complete treatment see Hool and Johnson's, "Concrete Engineers' Handbook," pp. 139 to 146.

The fabrication of beam and girder reinforcement into units before placing, similar to that followed for columns, will, in many instances, work out to advantage both in time and money.

After reinforcement has been placed, and just before pouring, a thorough inspection should be made to determine whether all metal required by the plans has been supplied, that the forms are clean, and that all inserts, hangers, pipes, and other auxiliaries are in their proper position. On combination arches, filler tile, if broken, should be replaced, and the tile which have been disturbed again brought into alignment. In extremely dry and hot weather, a drenching of forms with water just before the concrete is deposited, will prevent excessive absorption and consequent robbing of water from the concrete mix.

41. Handling and Storage of Concrete Materials.—Satisfactory construction in concrete cannot be obtained if slipshod methods are allowed to dominate the field practice. While the quality and selection of materials entering into the work are generally determined by the purchasing or contract departments, the burden of final responsibility always rests with the field organization, who by the acceptance of inferior materials, may entirely defeat the promises of the most carefully prepared designs. Not only is the quality of the various materials to be watched, but the method of job handling and storage should be so worked out that no opportunity for their deterioration is permitted after delivery and before actual use.

In this respect, different operations require different treatment. On some, it may be quite sufficient to rely on daily deliveries of the stone, sand, and cement required. On others, where delivery facilities cannot be so well depended upon, a stock reserve will have to be provided. This may be either ground storage with planks beneath to prevent contamination from earth and other foreign matter, or it may take the shape of bins, should the storage involved be sufficient to warrant their construction. On large operations, where concreting is proceeding more or less continuously, the use of hoppers or bins becomes almost mandatory, and this is particularly true where a direct rail delivery of materials is had to the job. For filling such bins, use is made of either the continuous bucket conveyor, skip buckets operated by a hoist cable, or the clam-shell type of grab bucket, the latter being the more flexible arrangement if the equipment is available and if also there is space within which to operate. If storage bins can be set up so as to feed direct to the mixer, a second handling and considerable labor will be saved.

Remembering that the useful performance of cement is brought about through its chemical union with water during the mixing with other materials, it follows that storage of cement, whether in bags or bulk, should be in dry, air-tight storage rooms. Cement is avid for water at all times, and exposure to dampness in any degree before use proportionately lessens its ability when called upon to give useful service. Cement may be delivered in bags, barrels, or bulk. The latter method has many advocates, and when its use is permitted, the greatly lessened labor cost of handling will usually compensate for any risks taken in shipment. For bagged cement, gravity unloaders leading from the car or truck to the warehouse floor can be used to advantage. Individual shipments of cement should not be allowed to collect and remain for extended periods in job storage. Even at the expense of extra labor, if that be necessary, the older cement should be identified and worked up at frequent intervals.

The important relation which exists between the value of the empty cement container and that commodity itself is quite often underestimated by even those who should be the most interested. With cloth sacks carrying a reclaim value of 15c. each, it can be seen that from 20 to 25 % of the initial cost per barrel is made up in this one item, and, as a consequence, any unaccounted for or damaged bags can produce a very marked effect on the cost units. One prolific source of loss comes through the original acceptance from the dealer of damaged or unsound bags, and a rigid inspection at time of delivery should be instituted to guard against such practice. Empty cement bags should be collected daily from each mixer, and suitably protected from the weather and against pilfering until they can be counted and bundled for return to the manufacturer.

The informal use of bags by workmen for protective coverings, foot wear, aprons, tool bags, etc., should at all times be prohibited.

Before building, each bag should be shaken in order to reclaim as much loose cement as possible. It has been estimated that the average waste per bag is ¼ lb. from this source alone. Mechanical bag shakers have been devised for this purpose, and are being successfully used on many operations.

42. Measurement of Materials.—In the proportioning and measurement of the several ingredients entering into concrete, recourse should first be had to the specifications. Here it may be found that the designing engineer has elected on the mix which he believes will most surely provide the unit strength on which his design has been based, and the conventional 1:2:4, 1:3:5, etc., will be established for the guidance of the builder. In such cases it is essential that the workman and those in charge understand and can place the proper trade interpretation on such requirements. Ordinarily, a barrow of stone or sand for charging purposes is taken at

2 cu. ft., while the commercial bag of American cement is taken at 1 cu. ft. Canadian cement being packed in lighter packages, it is customary to assume one and one-ninth bags per cubic foot. Under such specifications the water content or volume of mixing water is not, as a rule, specifically stated but is left to the judgment of the inspector or foreman in charge.

More recently, as the knowledge of "better concrete" has widened and the result of the intensive study being given to that subject by our universities and engineering institutes has become generally available, we find a growing tendency on the part of designing engineers to specify their concrete only in terms of strength. Such a move is decidedly in the right direction and should be encouraged wherever large or important work is involved. The builder, being presumably in better acquaintanceship with the local material market, falls back on his newly acquired knowledge in the theories of water-cement ratio, fineness modulus, etc., and develops that mix which is the most economical from the point of cost and with a certainty of performance that is far more dependable than the old method of arbitrary volumetric mixes. Many treatises in simple and understandable language, explaining in detail the mode of procedure for producing from the materials available a concrete of predetermined strength, are now accessible to all. Perhaps those that will be found most useful are the American Concrete Institute *Reports* of its Committee C6.

43. Mixing Concrete.—Mechanical mixers are now procurable in such sizes that any of the standard mixes can be run through at full batch capacity without resorting to split bags of cement. Water should be introduced only in measured quantities. Clean water only should be used, and having once found the quantity per batch required for the desired consistency, that amount only should be used for all subsequent batches that are formed from the same aggregate.

A daily count of all batches turned out by any one mixer should be kept by the workman, against which can be checked its total consumption of cement. If followed up consistently this will aid in detecting any departure from the uniform mix. Mechanical mixers are now built in so many different sizes that one will be found suitable for even the smallest of operations. As a result, hand-mixed concrete in these days has almost entirely disappeared from building construction practice.

For producting a predetermined-strength concrete, a somewhat more complicated mixing plant will be required, but the added expense of same will be found to be usually offset through the more economical use of cement which it permits. For jobs of sufficient volume a batch loader, through which the dry ingredients are automatically weighed into the mixer drum, will be found almost indispensible. The use of the sand inundater for preserving a constant moisture content is also a helpful adjunct as is also the water-measuring device. The latter should be positive in its control but at the same time easily variable in its adjustment.

To produce expected results it will be found desirable to reinforce the usual field organization with an *inspector* or *engineer* who will be given complete jurisdiction over the mix as well as over the materials of which it is composed, until it is discharged from the mixer. Such an inspector will sample his sand and stone daily, and maybe oftener, to determine its cleanliness, fineness, and moisture content. He will make frequent slump tests of the concrete as it leaves the mixer to check against his control behind the mixer. He will also prepare the cylinders from each day's run for laboratory tests 28 days later.

It is impossible to state, in general terms, the minimum yardage that would warrant the installation of a plant of this type together with its technical control. It can be said, however, that a contractor once acquainted with its possibilities, and having equipped himself with the necessary accessories, will be found using it in preference to old-time methods on smaller and smaller jobs. Eventually, it can be assumed that it will be the only acceptable method.

44. Transporting Concrete.—The safe and economical transportation of concrete from the mixer to the forms is a subject always to be accorded the most careful consideration—not that the proved methods are innumerable, or in themselves greatly at variance, but so that the particular concrete operation under study is viewed in the proper relation which it bears to the structure as a whole. If it dominates, then the mixing plant and transportation system will be given the first consideration and all other facilities are made subordinate thereto. On the other hand, if this particular placement of concrete is not the controlling trade, then that arrangement will be chosen which best lends itself to the general scheme of material transportation, all trades being considered.

Some elementary principles upon which the ideal transportation system should be based, have been summed up briefly by one eminent authority as follows: (1) that the time interval elapsed between reception of concrete and its delivery to forms will not cause it to dry, or to take initial set; (2) that the system shall be tight, so that the more

fluid portions may not be lost in transit; (3) that the mode of transit shall not permit a separation of ingredients; (4) that the delivery shall be approximately continuous, so that mixtures of varying composition may not be caused by stoppage and settling; (5) that it shall be efficient, rapid, and economical. In this summary, the order of importance is such as to emphasize quality of product delivered, as well as cheapness. With the foregoing in mind, the proper selection of the system, be it hand propulsion, vertical hoist, gravity, or a combination of the three, must be left to that individual best conversant with the situation, and responsible for results.

45. Placing of Concrete.—Hardly less important than the transportation of concrete is its placement in the forms. The placement should be such as not to permit the separation of the concrete into its component parts, as would occur if it were deposited continuously in one spot. Beams and slabs should be filled to the top in one continuous operation. When interruption to the work occurs, such as the end of the day's shift, stoppage should be made only at predetermined points where the security and safety of the work will not be affected. The general practice on floor slabs and beams is to make this at the center of the span with the stopping plane perpendicular and at right angles to same. Columns should be poured complete to the bottom of beams or girders in one operation, and then allowed to set before proceeding with the floor construction. When new concrete is deposited on old, special precaution must be taken to secure proper union.

While filling forms with concrete, too much attention cannot be given to the spading required if good workmanship is to be obtained. This action not only carries the heavier materials away from the face of the forms and so produces a denser and smoother surface, but it also eliminates to a large degree the air bubbles which otherwise form and if not removed account in part for porous work. The tapping of forms on the outside while concrete is being deposited is likewise beneficial in producing stronger work.

Concrete drippings from the runways, as well as any other material that has taken on the initial set, must not be mixed with the good, but should be rejected and removed from the building. At the close of a day's work, all mixers, buckets, spouts, buggies, runways, etc., should be thoroughly cleaned and flushed out with clean water. Particular attention should be given to mixers, and all accumulations of drippings removed while yet in a plastic state.

45a. Bonding New Concrete to Old.— True union between new and old concrete is difficult to secure. This difficulty increases as the water content of concrete is increased, both by tending to produce a film or layer of fluffy laitance at the top of the concrete first poured and also by diluting the cementing solutions in the new concrete, which solutions furnish the attaching or bonding means by contacting with and entering into the old or set material.

Customary recommendations are: (1) To roughen the old surface, (2) to thoroughly wet it, and (3) to coat it with a paste of neat cement, well rubbed in, before pouring the new concrete. These have a sound basis, except: (1) that the depth of the roughening or removing old material should be so specified as to give assurance that clean, sound material, without dirt or laitance will be exposed; and (2) that the surface should be *dry*, not wet at the time the cement wash is applied, as wetting fills the pores in the set material with a fluid unchanged by cementing products and makes weak the cementing solutions directly at the plane of contact where they should be strongest for the result desired.

46. Finishing Concrete Surfaces.—Exposed surfaces of concrete require different treatments according: (1) to the excellence of their materials and workmanship, and (2) to their exposure and the character of their service.

The first of these is, as always, of chief importance. Thoroughly first-grade concrete, well placed and true to line, needs little or no finishing after it has set, except where architectural reasons require some special finish, such as, a matt, bush hammered, re-cut, or exposed aggregate finish. Inferior or careless work, on the other hand, necessitates long and arduous labor to make it presentable and useful.

46a. Removing Form Marks.—Careless building or bracing of forms always leaves a multitude of fins, edges, and blemishes. Fins may be readily removed by hand labor with hammer and chisel. Edges may be removed in like manner, but only with patient and careful labor. Blemishes, such as wood-graining, etc., can either be ground off, or can be effectively concealed by brushing with a wash of neat cement in water. Blemishes left by cutting off tie wire may be concealed by painting carefully with cement mortar before the cement wash is applied.

46b. Repairing Surface Honeycomb.—Honeycomb is commonly viewed with lenience, but it is one of the surest evidences of poor workmanship in placing concrete. Accord-

ing to its location and the character of materials used in the concrete, it may or may not indicate a serious weakness. If strength is not impaired by its extent and presence, it may be concealed more or less permanently by painting or plastering over with cement-sand mortar, with a final cement wash to blend it into adjacent material. Such methods are, however, apologies at best. Honeycomb should properly be cut out and replaced with sound concrete.

46c. Grinding Concrete Surfaces.—When concrete is moist and green, it is treated more easily than when dry and hard. Grinding of green surfaces may be readily done either by hand labor, using carborundum bricks, or by electric machines marketed for these purposes. Grinding makes a very effective finish where the cost is not prohibitive.

46d. Grinding Concrete Floor Surfaces.—Where "dusting," or other surface defects are found in concrete floors, grinding off from 1/16 to 1/8 in. is the surest and most effective remedial means. The dusting of concrete floors is usually caused by the use of excess water in the making of the concrete, or else by excessive ramming or floating. Removal of the loose-textured surface in such cases is necessary for lasting relief. Grinding machines, usually electrically driven, perform the work quite efficiently, though the process is tedious at best. Temporary relief may be had from chemical "hardeners" marketed under various trade names.

46e. Special Surface Finishes.—Tool-cut surfaces may be obtained in the usual way where cost is not prohibitive. Stippled surfaces, or exposed-aggregate surfaces may be obtained by wire-brushing the concrete when green, or by acid washes, or by both. The effects obtained can be greatly varied by the selection of various colors of aggregates and the means of treatment adopted.[1]

47. Concreting in Hot and Cold Weather.—During hot weather, excessive evaporation is liable to dry out the concrete before the cement has had a chance to set. The usual procedure under such conditions is to keep the work moistened and protected against the direct rays of the sun by a covering of some sort, such as sawdust or canvas.

In cold weather, even before the actual freezing point has been reached, it is customary to take special precautions. The day's work should not be started until there are indications that there will not be a sudden or decided drop in temperature, and the work should be suspended sufficiently early in the day to permit of proper protection from the cold nights and possible frost. This can be obtained by spreading out a coating of straw, canvas, or even sand and cinders, if they are being used on the work. When work has to be carried on below the freezing point, and 20 deg. is about the limit, artificial heat will have to be supplied by means of coke or coal fires in salamanders, the heat thus produced being confined within the building by a liberal use of canvas, or other protection around the exterior at the level at which the work is being carried on.

When working under extreme conditions of this nature, the preheating of water and aggregate will be found necessary in order that the concrete shall not freeze before it reaches the forms. Steam coils or live steam is the usual method of providing the heated water. Sand and stone if received at the job in a frozen condition, must be thawed out before being placed in the mixer. A wood fire within a metal drum or old section of smoke stack, and around which are piled the frozen lumps, is perhaps the most satisfactory method. Steam jets are helpful in working out frozen car loads or piles of sand and stone.

48. Floor Arch Systems.—Most floor arch systems are called upon to provide concealment for horizontal pipe runs, conduits, etc. In concrete construction these pipes are often embedded in the arch itself. In tile construction, they must be run in a fill, generally of cinder concrete laid on top of the arch for that purpose. If the former system is being used, then the electrician, plumber, and any other pipe trade, whose lines may be involved, should be on the building with materials and full information, so as to install his work directly the centers have been erected. If the second method is being used, then the lines will not be required and should not be laid until means are provided to protect them with the concrete fill. On concrete arches where the upper surface provides also the floor finish, it is customary to complete the trowel or float finish at the time the arches are poured. When the cinder fill intervenes,the finish being cement or hard wood or strips, the arch only is installed at this time, leaving the balance of the work to be followed up by succeeding trades and at a later date.

[1] See "Concrete Engineers' Handbook" by Hool and Johnson for detailed treatment.

In the bar joist system, generally used in connection with steel-frame structures, which is finding increasing favor in several sections of the country, no centers are required. The reinforcing mesh which is stretched across the top of and clipped to the individual joists is of sufficient density to prevent excessive leakage through of the concrete which forms the slab and which is deposited directly on the top of the mesh or hyrib. The joists are attached to the supporting girders by hangers, the actual connection being accomplished most readily by spot welding. Owing to the light thickness of the slab used in this system, generally 2 in., it may be found that all of the pipes and conduits cannot be embedded therein, and certain of them will have to be run beneath the slab. If the beam joists are of the open type of web, no difficulty is encountered. If, however, the solid-type web is used, clearance for pipe lines must be provided, and this is accomplished by coping the joist ends on a bevel down and away from the top flange and the supporting girders. By keeping all pipes and conduits in the slab or within the depth of the joists themselves, the ceiling lath for the story below may be clipped direct to the lower flanges of the joists.

Whether this floor fill should be placed before or after the ceilings are plastered, is dependent upon individual conditions. If the work is being done in winter weather, it is preferable to lay the floor fill first, thus obviating any possible damage to plaster ceilings below through dampness and freezing. In summer work this element is not present and if due precaution is taken not to permit the tamping of the fill into place to break the plaster bond below, then the plastering should be completed first.

Another consideration which sometimes holds the determining value, if viewed from the standpoint of economy, lies in the size of the various rooms in which the floor is to be divided. If the spaces are small and badly cut up, then it will be found much cheaper to lay the fill and finish as a loft floor holding back the dividing partitions and plastering for the next operation.

In the construction of floor systems each level should be completed in itself as far as possible before proceeding to the next, only such open spaces being left behind as are absolutely unavoidable. If the lower stories are to be devoted to construction driveways and to temporary storage of materials, the arches should be first installed and then planked for protection. It is not advisable to plank first and depend upon getting the arches in at a later and more convenient date. That time will never come and will only result in throwing the entire building out of sequence and step. The same holds true as well for upper levels.

Floor finishes of wood, cork, rubber, linoleum, etc., should never be laid until all danger of dampness from plaster or floor has been eliminated. A small piece of roofing felt or building paper laid upon the floor fill and sealed against the action of the air with a non-absorbent material will upon inspection a few days later disclose the amount of dampness then prevalent in the building. This is a simple test and should be made use of before proceeding to install expensive floor finishes.

CONSTRUCTION IN WOOD

BY HENRY D. DEWELL

Many of the features of the contractor's plant for the construction of a timber-framed building will be the same as for the erection of a building with steel or reinforced concrete frame. For example, it should be obvious that in all construction jobs there should be an orderly arrangement of plant with proper facilities for receiving, checking, and storing material, also for delivering the material from the general storage yard to the various points of fabrication. The detail method for accomplishing this work will depend largely upon the size and character of the building. Further, it is hardly necessary to state that some simple method should be put in force for keeping the cost of the various parts of the work. These remarks may appear to be commonplace. Unfortunately, there is a tendency, when dealing in timber construction, to be careless in both arrangement and character of work.

49. Storage of Material.—In the case of a concrete building, since the lumber for forms is only used temporarily, no particular provision for preventing incipient decay or rot need ordinarily be taken. On the other hand, for permanent timber construction, all lumber when received on the job, should be immediately protected from the weather and also from contact with the ground. Timber when in contact with the ground may soon become infected, with the result that disease will start and may continue after incorporation of the timber with the building, if conditions are favorable to growth of fungi.

All lumber should be segregated into the various sizes and lengths, and carefully piled on firm level foundations with supports at intervals not exceeding 4 ft. If unseasoned, the lumber should be "stuck," *i.e.*, the pieces in any

one layer separated by a 1- or 2-in. air space, and each layer separated from the upper and lower layers by means of 1-in. cleats. In "sticking," care must be exercised to see that the "sticks" or cleats are placed directly over the foundation sills throughout the pile; otherwise, the timbers will be warped. Finally, a temporary roof should be constructed over each pile, the roof projecting a foot or two over the sides and ends of the pile. The best lumber can easily be ruined by careless piling and exposure to sun and rain, and any warping results in increased cost of framing.

All iron work, such as truss rods, castings, washers, plates, etc., should be arranged in neat piles and plainly labelled. Bolts should be segregated into the various diameters and lengths and placed in a bolt rack, with each size and length numbered.

50. Working Details.—Working or field details should be provided for all timber construction. This statement applies particularly to those buildings involving roof truss construction. Very few plans for timber-framed buildings give full and sufficient details of all connections. This practice results, in part at least, from the common procedure in the preparation of plans for steel-framed buildings, where the designer prepares only "contract plans" and relies upon the contractor to furnish "shop details" for approval. When such a designer has a timber-framed building, he works along the same lines, preparing, as usual, the "contract plans," and the "shop details," if any, are comprised in the contractor's drawings of the incidental steel work.

Time and money will be saved in all timber-framed construction, except the very smallest and simplest, if full working details are prepared. These details should include an erection plan, details of all joints, cutting lengths of all timbers, details of all metal work, lengths and diameters of rods and bolts, etc. Letters and numbers should be placed on the plans for all members, and a complete detailed list of materials made with the letters and numbers repeated from the plans. The different materials in the storage yard should then be designated with the same markings, so that a workman can instantly find any piece of material shown on the plans.

51. Methods of Construction.—Two methods of construction may be mentioned: (1) fabricating all material before erection is started, and (2) erecting material as fast as it is fabricated. The second method is preferable as it enables the contractor to realize on his work at the earliest possible moment.

In any event, the first floor should be constructed as soon as possible, with the rough floor in place, in order that all trusses, posts, etc. may be laid out and fabricated on the floor. A smooth, level floor is preferable for such purpose to any fabricating platform that can be constructed.

The center lines or outside lines of trusses should be laid out on the floor to actual sizes. Sometime templates of all timber members are constructed and the actual members cut directly from these patterns. In other cases, no templates are made, but the members are cut from the figured dimensions or the dimensions scaled from the full size layout. The template method is to be recommended. It may seem an unnecessary expense, but will avoid many mistakes of cutting members too short, cutting daps at the wrong places, etc.

In laying out a truss, the outside lines of timbers should be used as working lines, and all dimensions figured from them. For example, given a lower truss chord 12 in. deep, with diagonals framing into the upper side to various depths, as ¾ in., 1 in., etc. Instead of measuring such cuts from the upper side, the measurements should be made from the lower side. This will take care of all variations in width of the timber chord and will enable all similar diagonals to be cut to the same length.

52. Camber in Trusses.—Most specifications for timber trusses call for camber to be given to the trusses. This camber is usually specified in terms of camber per linear foot of truss, as ½ in. for every 10 ft. of span. Camber in ordinary roof trusses is usually introduced by springing the chords on the fabricating platform to approximate arcs of circles and cutting the diagonals to fit. In other instances, especially in small trusses, the trusses are framed with straight chords, and joints left somewhat loose, and the whole truss then given an approximate camber by tightening the rods. Such a method, it is obvious, does not give a real camber to the truss, and if the truss, after erection, retains any of this so-called camber, it is due solely to the restraining action of the posts or walls. If true camber is to be introduced in a truss, the members must be cut accordingly, and all joints made tight before erection of the truss.

53. Equipment.—The question of amount of machinery and tools can only be determined by the character and size of the job. In general, it will always pay to provide sufficient tools, and power machinery will save much labor. However, more than one job has been a loss on account of too great an investment in plant.

When there is much boring to be done, power drills should be installed. These are of two kinds, electric and air drills. Of the two, the latter are the more satisfactory, but in many jobs the contractor will hesitate to install the necessary air-compressor plant. Electric drills are preferable to hand boring, but are heavy and somewhat cumbersome. Many of them operate on but one speed and do not reverse. With such drills, difficulty will be experienced in driving long holes, since the drill will tend to stick, and the drill must be constantly and expertly fed into the hole.

A small cross-cut and ripping saw may well be installed on jobs of some size, especially where there is much duplication of typical members.

54. Erection.—Hand power is the most expensive that can be used for erection. In buildings involving truss work, some form of traveller or derrick should be installed, even if only operated by a hand winch. It is hardly necessary to state that the work should be so arranged that once erection has started it can be carried on continuously. All fabrication of members should be done as completely as is possible on the ground, leaving the least amount of work to be done after hoisting.

STONE WORK

By A. G. Moulton

The term masonry as referred to building construction, generally implies stone or brick work only, and is quite distinctive from cement work, fireproofing, plaster, or marble, each of which is treated under separate specifications despite their requirement of the trowel as a common tool.

55. Use of Building Stones and Stone Masonry.—The use of stone masonry for foundation walls and piers below grade is now seldom met with, the more economical material—concrete—having displaced it with the rapid building up of our cement industry. Above-grade stone is now used largely for ornamental purposes. Beginning with the field stones and boulders used in garden wall and residence work, and carrying through to the higher ornamental and carved marble employed in our more ornamental buildings, all kinds of quality of stone masonry will be encountered by the builder. The limestones, sandstones, and granites, however, are those most commonly used for exterior facings.

In localities convenient to the quarries, it is not uncommon in wall bearing structures to run up the entire thickness of the wall in stone, bedding furring strips at proper intervals for cross-furring and lath to be applied later on the inside face. If the stone is not a local product and freight enters into the cost, then it is more usual to reduce its thickness to that minimum required for its use as a veneer, and to bring up the wall to its full structural strength and thickness by a backing of brick work or other product of the kiln. For use on skeleton constructed buildings, where minimum construction weights are such a determining factor, its use as a veneer is the only one practicable.

56. Preventing Stains on Stone Work.—When cement mortar is used as a bedding, extreme care should be taken to select only such materials as will insure freedom from stain working out and disfiguring the face. Many so-called nonstaining cements are now on the market and are used for this purpose. The use of dirty sand may be as fully disastrous as a poor selection of cement and should be guarded against. Other protections against stain on the face are obtained through back painting with an asphaltum paint, or by plastering with a trowel coat of nonstaining cement mortar after the stone has been set and before backing up. Either or both of these methods is particularly essential if the backing is carried up in common cement mortar. Limestones are the easiest to stain, and when working with them, the most careful supervision should be accorded if good results are to be obtained. The Indiana Limestone Association specifies the use of a nonstaining cement and does not permit back painting of the limestone.

57. Setting Stone Work.—The equipment for setting stone work varies with the type of building and the quantity of work involved. For rubble walls, either random or course, no particular equipment or plant will be required except for scaffolding to keep the mason abreast with his work, and stone barrows for delivering the stone within reach. An "A" frame for handling large sills or lintels may be useful. For course work where the size of the individual pieces exceeds the capacity of the mason and his helper to handle individually, the "A" derrick with hand winch or drum is usually resorted to for all walls not exceeding three stories in height. When supplied with a good firm run plank, it is rapidly shifted from point to point and but two

back guys are required, composed of one continuous piece of line running through three single sheave blocks, the two outer ones of which are attached to the head of the derrick, the center riding in the bight of the line, and will be attached to some convenient point at the foot of the derrick by means of a small watch tackle. The two outer ends of the line forming the guys are attached to suitable anchorage, a suitable sufficient distance back from the foot of the derrick to overcome any tendency to kick, and sufficient spread to avoid constant changing as the derrick is moved along the face of the work. By manipulating the watch tackle, one man at the foot of the derrick can control its action at all times.

58. Handling Stone.—Stones are picked up by the "Lewis" anchor or, where the "Lewis" holes would be objectionable such as in sills, by means of stone dogs and tongs. One mason and three riggers constitute the usual crew for such a derrick. Special dowel and anchor holes for inserting metal ties to bind in with the backing are generally cut in the field, and for this purpose one or more cutters will be required on a job of any size. They will also be required for fitting and back checking to overcome unusual conditions impossible to foresee at times of detailing. For high buildings, exceeding three stories, boom derricks are usually depended upon. On skeleton construction, the Chicago type of boom is used and a sufficient number installed to swing the entire frontage that is to be set. They should be hung as high up on the steel work as possible without getting in the way of the steel erectors, thus minimizing the number of jumps required to complete the entire front. To await the final completion of steel work and then set derricks on the roof, injects needless delay in the building's construction, and should not be considered. The power applied may be mechanical—supplied by steam or electric hoists—or it may be manual, obtained through the air of hand winches or windlasses set on the floor at the level of the derrick. For most work, the mechanical power is more desirable.

For wall bearing structures exceeding in height the range of the "A" type derrick, recourse is had to boom derricks set on platforms elevated by means of suitable towers. Such derricks will generally be set within the building lines and will be used in common by other trades whose work is dependent upon the progress of the walls.

On colonnades and other monumental fronts of sufficient length to warrant it, a device known as a "traveler" mounted on trucks and rails parallel to the building front, may be found useful. In effect, this device is an elevated, moving platform, self-sustained, on which is mounted one or two stiff-leg derricks with revolving booms. The dimensions on such a traveler are, of course, dependent on the range of work to be covered.

Inasmuch as the progress possible is directly proportionate to the number of setters employed, it has been found convenient on high buildings, where the element of time is a governing one, to dispense with the Chicago booms, which do not operate advantageously on closer than 60-ft. centers, and substitute therefor the short "A" frame type, working from the inside and setting out. These used in conjunction with chain falls permit the use of a setter on each and every pier, if necessary, and very rapid headway is thus accomplished. For this purpose the unset stones are hoisted to the various floor levels by large boom derricks, either as individual stones, if they are large, or in stone boats if they run to smaller sizes. They are then sorted on the floor and trucked or rolled out to the particular panels in which they are to be set, and there picked and dropped by the small "A" derricks to their final resting place.

59. Pointing Stone Work.—Stone work as a rule is not pointed as it is set. That operation is handled in conjunction with the cleaning down after the work has all been set out. Exterior hanging scaffolds are used, and starting at the top the work is thoroughly washed with clear water and stiff brushes. Although the use of washing powders is permissible, the practice of using acid, even in weak solutions, on any kind of stone, should be seriously condemned. All drippings, particularly on sills and projecting courses, should be cleaned off and all wooden wedges inserted by the setters should be removed. On limestones, a dry brushing with stiff wire brushes gives good results.

The pointing should only then be completed, using that type of joint selected, excessive care being exercised to see that the pointing mortar is shoved well back into the open joint to provide proper key.

60. General Precautions.—An observance of the following points will be found beneficial:

All lug sills should be bedded on ends only, leaving full clearance through entire length between jamb lines.

All metal anchors, other than those composed of brass or copper, should be thoroughly painted with some rust resisting preservative before inserting in the stone.

Overhanging courses should be provided with temporary support from below until sufficient weight of wall has been applied above to prevent tipping out.

All projecting courses and finished horizontal surfaces should be boxed and protected until danger from falling materials above has ceased.

Clean white sand only should be used in the mortar.

Stone should not be laid in freezing or frosted weather. If the work must go ahead, then all known precautions should be taken, otherwise spoiling of the face will result.

Vertical joints in coping sills and projecting courses should be pointed full depth or grouted to give a complete seal against the weather.

When piling stone in the sorting yard, on the floor, or on the scaffolds, a firm, clean foundation should be provided and all setting identification marks exposed, so that the different pieces may be quickly recognized and obtainable without extra handling.

The endeavor should be made to have the work backed up as far as set out before leaving it for the night.

Carving may be done either before or after setting. On large panels built up from small pieces, best results will be obtained by carving in place. There may also be considerable time saved by this latter method, thus compensating for the expense of scaffolds and protection to the carvers which otherwise would not be required at the building.

BRICK WORK

By A. G. Moulton

Bricks in one shape or another are common to nearly every type of building construction. They are used for structural as well as ornamental purposes. Used structurally as in bearing walls, it is seldom that the masonry will exceed 21 in. in thickness. From that down to 8 in. is the usual run of the work for the wall proper, with a 4 or 8-in. pilaster added to points where load is applied.

61. Location of Mortar Supply. The mortar box, or mechanical mixer, as the case may be, should be set up so as to average the wheeling distance so far as possible to all points of the work proper. Its location also should be convenient for the delivery and storage of the dry ingredients and also close to the water supply.

Under ordinary conditions and where not over 12 masons are employed, hand-mixed mortar will be the most economical. Where from 12 to 20 masons are employed, either hand or machine mixed is equally good. For more than 20 masons, a machine mixer of the continuous type will give the best results.

62. Bonding Face to Backing.—For enclosing walls, the outer 4 in. may be carried up with a so-called face brick to obtain the desired architectural effect. The bond between the face and balance of the wall is accomplished in one of many ways and is generally a matter determined by the specifications.

63. Scaffolding.—For stories of ordinary height, a horse scaffold, composed of the familiar 4½-ft. mason horse and 5-plank deck, will be found the most convenient. Two sets high of this construction is the practical limit, however, except for short stretches. Hence, when walls exceeding 14 ft. between floor levels are encountered, it will be best to use the putlog scaffold composed of one line of upright supports at convenient centers (approximately, 7 ft.) set parallel and 6 ft. from the face of the work. Cross supports are attached thereto with inner ends bearing 4 in. on the wall and upon which the deck planking is laid. As this scaffold is dismantled, the putlog holes are filled up by the mason. This type of scaffold properly cross-braced will answer for almost any height of wall.

For face work, it is desirable to provide an outside scaffold if best results are to be insured, and particularly if a different kind of mortar is used on the face work from that used on the backing. All joints on face work should be struck, pointed, or raked out, according to the chosen design as the work proceeds and all backing should be copped out level with the face work, and the wall provided with temporary covering for weather protection before suspending for the day.

64. Swinging Scaffolds.—For steel frame buildings, the patent swinging scaffold has become almost indispensable. Outriggers are projected along the face of the wall from the highest point available on the steel frame. These in turn support the scaffold machines, which are essentially small cast-iron drums actuated by trailing hand rope through the medium of worm gear and sheave. Wire cables attached to and suspended from the drums carry the scaffold proper. The cable capacity of the drums, usually 125 ft., determines the height the scaffold may be raised without resetting the outriggers and machines. The hand control ropes

being of equal length to suspension cables, are always in reach of the scaffold men, who are constantly patrolling same and keeping it abreast of the walls and to the best advantage of the mason. Overhead protection, in the shape of light decking, should be provided on all such scaffolds whenever other trades are working at higher levels. The outer edge of the scaffold should be protected with a guard rail and light fence of poultry netting together with toe board.

On high buildings it has been found entirely practicable to keep the exterior walls within two stories of the finished floors at all times, providing all necessary materials have been properly scheduled for delivery as required.

If, due to unusual conditions, a delayed start is made necessary on the walls whereas the steel frame and arches have kept to normal progress, the gap thus produced can be closed by putting out a second scaffold at a higher level and working from both concurrently. To do this successfully, however, requires ample and well laid out hoisting facilities, so that no delay will ensue to the different sets of masons through waiting for materials.

65. Serving Materials to Masons.—The proper serving of materials to the mason while working from scaffolds is one of the most important factors to be watched. A scaffolding should be arranged so that the brick can be wheeled from the stock pile on the floor and by one transfer taken from the barrow and laid at the mason's feet. This arrangement, however, should not be at the expense of a heavy pull up a steep incline or runway. Under such conditions, two passes of the brick are to be preferred. Beyond this point, the brick hod must be depended upon. By keeping an even, constant flow of brick to the mason, not crowding up on him so as to restrict his foot space on the scaffold, and by keeping the tray always full of mortar, is the best way to insure satisfaction in the ranks and promote consistent output.

66. Material Elevators.—Brick, mortar, and other materials entering into the construction are elevated to the various working floors by means of platform hoists running up through temporary hatchways left in the floors, or in towers erected on the outer face of the work. Single platforms with capacity for two wheel barrows at a time are favored over the up-and-down type with one barrow to the load, because of the greater traveling speed obtainable. From 800 to 1000 ft. per minute is possible with the former type, and a greater margin of safety is provided for the operators. It is needless to say that riding on material hoists is an extremely dangerous practice and should not be permitted under any condition. For buildings over 12 stories high, it is customary to provide a temporary passenger elevator for the convenience of the workmen. This is generally erected in one of the permanent elevator shafts, using one of the permanent machines for motive power. On very high buildings where it will be impracticable to wait for completion of machine supporting steel, a temporary basement type machine is used.

67. Progress of Work.—The average story of front brick or terra cotta, or a combination of both, will be run up in about 10 hr. work, or about 4½ stories a week. Under more favorable conditions, a story per day has been accomplished.

As soon as the front has been topped out, the patent scaffold should be removed and the cleaning scaffold swung out. Ordinarily it is not practicable to set the lookouts for handling scaffolds so that they may be utilized for the cleaning down process as well. However, that possibility should be studied and taken advantage of whenever advisable.

MECHANICAL TRADES

By A. G. Moulton

68. Sequence of Trades on Building Operations.—The proper time for the pipe trades to take up their work on a building will quite naturally vary with the character of the structure. Generally speaking, it must be at such a time as will preclude any possible delay in the starting of other trades, and they should also be worked in so that a minimum of cutting and patching is provided for.

69. Plumbing Work.—Freedom of working space and plenty of daylight in which to run pipe work are excellent factors in keeping down costs. For this reason it will be found desirable to run in risers, such as plumbing, steam, electric and ventilating, just as soon as the supporting frame work of the building becomes available. On the same theory, horizontal lines and branches, such as suspended sewers, soil lines, steam mains, etc., will, if withheld on instal-

lation until floor arches are in, call for noticeably higher labor costs than if they were hung in the open immediately after beams are in place.

Vertical soil lines, down spouts, sprinkler risers, steam and return lines, electric feeder conduits, etc., if run ahead of the arches will always be reflected in a lessened cost to the building as a whole, although in individual cases some of the above piping trades may be put to slightly additional expenses in providing necessary scaffolding to insure the safety of the workmen. The real saving comes in the cutting and patching which is thereby obviated.

In following this method of advanced pipe work, thorough supervision must be given by the interested parties throughout the time that centering and arch construction proceeds, to see that the various risers are kept in proper alignment, and that all required sleeves are in proper place and at correct level before they are permitted to be built in.

70. Importance of Pipe Drawings.—In order to take the fullest advantage that the situation offers, it will be seen that all pipe sketches will have to be worked up and cut out, all main and branch lines detailed and fittings ordered, and such other items as hangers, expansion sleeves, panel and cut-out boxes, special valves, etc., be arranged for on specified delivery dates to insure their availability within the very limited time that exists between the time the structural frame work of the building is ready to receive them and the following on with the arch construction.

71. Advantages of Plumbing in the Open.—In addition to the economies of installation, there is another very pressing need for advancing the roughing period of the plumbing installation to the greatest extent. Most municipalities require a specified test for tightness on all sanitary lines before their concealment. This means that the minimum number of stories which can be tested at one time sets the distance which the interior partitions and furring must be kept back of its normal position, which ordinarily is immediately following the exterior wall enclosures. If the plumbing installation has been advanced so that a sectional test is had at about the time the fourth or fifth floor arches are built, then no delay will ensue and the progress of the entire building has been benefitted.

With the vertical lines and main branches out of the way, the mechanical trades will be in the most favorable position to take up the lesser branches, run outs and circuits, either in conjunction with or directly following the arch construction, depending upon whether the design provides for the embedment of pipes in the arches or in a fill supported by the arches.

72. Work in Conjunction with Floor Construction.—The steamfitter has his radiator branches to run at this time. The electrician, in addition to his floor circuits, should lay out and install the conduit for all outlets and switch legs, and any other work which later will be concealed in partitions, column covering, and furring. The plumber will be roughing in the supply vent and soil lines for sanitary fixtures. The somewhat common practice of allowing tile, partitions, furring, etc., to be erected in advance of pipe work, later to be cut or chased out for its reception, has little merit other than the relief it affords the mechanical trades from the responsibility of laying out their own work, and therefore should not be permitted.

73. Finishing Plumbing, Steam, and Electrical Work. The proper finishing period for the three mechanical lines which we have been following, and which would include radiators, valves, heat controlling devices and pipe covering for the steamfitter, sanitary fixtures and trimmings for the plumber, and panel boards, receptacles, switches, switch-plates and wire for the electrician, will naturally take their normal sequence after completion of finished floor, plaster, and marble work.

On buildings and structures where the pipe work and conduits are not required to be concealed, then a later start is not only permissible but will probably be desirable. There as above, however, the cutting and patching feature and its elimination should be the guide.

ELEVATOR AND STAIR WORK

By A. G. Moulton

74. Value and Importance of Early Installation of Elevators and Stairs.—Two important trades, both of which should be placed on the work at an early date, are those concerned with elevators and stairs.

Elevator guide brackets should be available, so that they may be installed and followed by the guides themselves within a period but a few days longer than that required to build the supporting steel work of the building. This is particularly true of lofty buildings, where it is customary practice to have the elevator machines prepared in time to be hoisted by the steel erector's derricks to the machine room level just before they are closed in for dismantling. Thus, with machines in place, and guides erected, temporary cars for freight and passenger service may be depended upon almost as soon as the roof of the building has been enclosed.

If, during the time the platforms are being assembled and connected up, the elevator shafts can be plastered, this should be done, even at the expense of some little inconvenience and disarrangement of other trades. Not to accept the opportunity at that time will unfailingly cause the forced suspension of elevator service at some later date, when it can be least afforded, in order to go back and finish the shaft walls.

In order to start guide work before completion of steel, two or more set of templates will have to be made; and in such cases it will be necessary to guarantee to the elevator constructor the alignment of all steel work surrounding the shafts, the greatest variation permissible being agreed upon and arranged for.

On high buildings, open and direct access by means of stairs to the various floor levels is a very important factor. Not only is the safety of the workmen involved, but a tremendous amount of time otherwise lost to employees can be accounted for, as against when ladders or other makeshift means are depended upon.

75. Erection of Iron Stairs.– Ordinarily, for high steel buildings, iron stairs are specified. Treads and platforms may be all metal or of pan type to receive a finish of composition, slate, or marble. When these stairs are designed for painted finish, no great harm can occur to them during the construction period, and they should be available and erected in the building as rapidly as the erection of steel will permit. It is not uncommon to keep stairs of this type within three floors of the steel derricks at all times. Temporary 2-in. plank treads are supplied and also temporary wood railings are used should the finished balustrade be unsuitable to install at such an early date.

For stairs which have a baked finish, or are made up of softer metals than iron, it will probably be found better to withhold their erection until the building is in the finish stages, using instead temporary wooden flights.

76. Installation of Ornamental Iron with Stairs. At the same time stairs are going in, elevator facias, if required, can be installed, which, together with store fronts, window mullions and other miscellaneous iron work, will generally provide continuous work for the ornamental-iron workers despite their early start on the stairs. This provision for continuity of work is a point to be kept in mind when scheduling all trades.

77. Protecting Elevator Shafts and Stairs.—The proper protection of elevator shafts, stairs, runways, etc., from a safety point of view, is a matter that should not be left to chance, as it provides responsibility of sufficient importance for the building superintendent himself to assume. Daily inspection should be made to determine (1) whether all required protection in accordance with accepted standards has been provided, and (2) whether proper upkeep is being maintained.

Temporary hod and material hoists are particularly dangerous features of a building under construction, and they should never be operated until the shafts are enclosed through which they run. If not otherwise protected by permanent walls, they are first fenced in with suitable enclosure on three sides at all floor levels through which they run. That side from which they serve and are served should be protected by a gate or protecting bar and this barrier kept in place on all levels except the one being worked. All enclosed stairs, dark passages, and basement runways, whenever open to the passage of workmen, should be provided with safety lights and railings.

Bell men for signalling the hoisting engineer should be chosen with due regard for their knowledge of the position and proven ability to follow instructions. Riding on material hoists of any kind should be strictly prohibited. For the enforcement of this rule, signs alone cannot be depended upon. They should be backed up by positive and concise instructions issued to all operating foremen and engineers, with the full penalty for violating thoroughly understood.

The value of a careful and thorough study of welfare and safety conditions and its effect on building construction work is rapidly becoming more and more a subject of deep interest to the builder. On work of large volume, it has now become almost universally the custom to reinforce the construction organization with one or more safety inspectors, trained to detect the dangerous spots and provide suggestions for their removal or improvement. On

work of lesser volume, where a separate department would not be warranted, these duties should be definitely assigned to some responsible individual in the organization, together with sufficient authority to insure the carrying out of his recommendations.

SEQUENCE OF FINISHING TRADES

By A. G. Moulton

Interior dividing partitions, wall furring, column covering, etc., should follow as closely after the completion of exterior walls as roughing or pipe trades will permit. In conjunction therewith will be required the bucks, grounds, and other items of rough carpentry incident to preparing the building for such of the finishing trades as plaster, marble, and trim. At this time also it may be desirable to install the exterior window sash, particularly so if the work is in or approaching the winter months.

78. Wood Trim, Flooring, Glazing, Etc.—Interior wood trim, maple flooring, glass, and hardware should be brought on the building only at such a time as they may be installed with safety. Ordinarily, this will be 3 to 4 weeks after plastering has been started. With metal trim no delay is necessary and the work may be executed as soon as the plaster is hard.

79. Setting Radiators, Plumbing and Lighting Fixtures, and Painting.—During this period the radiators are set and permanently connected up, plumbing and lighting fixtures are installed, painting of exterior and interior wood and metal surfaces is begun, finished floors are scraped or rubbed, as the case may be, and a general canvass of all incompleted items made to determine what is missing and the reason therefor. So called "Punch lists" giving this information and covering each branch or trade employed on the work, should be compiled, and checked against by daily inspections until the lists have been eliminated.

The proper time at which to institute these lists is a matter for careful consideration. If resorted to early, they must of necessity deal largely with generalities, and as such will fail in receiving the respect, or commanding the power that they should be entitled to. To be of real service, they must cover the ground in most minute detail, and until this can be done without becoming burdensome to the various trades, they had better be withheld.

80. Plaster and Marble Work. Plaster work and marble work are two trades which carry on together, where they engage one with the other, and either may be given the preference on installation with about equal results, time and economy both being considered. While it might seem that the necessary cutting and patching of plaster to bring the marble into engagement would be expensive, this item will be found to be just about balanced by the additional expense involved in protecting the marble should plastering be done last; added to which would have to be accepted a certain amount of lost time due to using the slower trade as pace maker. It is the latter consideration which generally permits the plaster to precede the marble.

With marble as well as with all trades, too much cannot be said about the extreme importance of scheduling materials for delivery in proper sequence that will meet job requirements. When dealing with fragile materials such as marble, due consideration should be given to the proper amount, if any, of stock pieces that should be provided in order to get out replacements on the job with the least possible delay.

81. Cleaning Up after Plaster Work.—Directly after the marble and plaster work has been completed on a floor, this section should be given a thorough broom cleaning and all surplus plank, building materials, rubbish, and other useless equipment should be removed from the story. Thereafter it should be kept in that condition as a clean building is not only the simplest, but it is the surest method of protecting the finished surfaces.

Marble treads, thresholds, and other surfaces subject to traffic may be helped out by a temporary coating of plaster of Paris, but beyond that and the usual precautions against oil and tobacco stains, the greatest dependence can be placed on the cleaning gang provided their work is conscientiously carried out.

SECTION 6

CONSTRUCTION EQUIPMENT

Mechanical equipment for modern building construction is available in such variety that it is possible in this "Handbook" to mention types only with general remarks on their field of application and their respective abilities. Care has been exercised to present a minimum of statistical detail as relates to capacities, dimensions, etc., inasmuch as manufacturers are constantly making changes in their equipment. Only so much of such data is given as will assist the reader adequately to visualize the equipment.

EXCAVATING EQUIPMENT

By Waldo G. Bowman

1. Earth Excavating Equipment.

1a. Power Shovels.—For building foundation work, the full-revolving power shovel is the standard tool when the volume exceeds about 800 cu. yd. The depth of excavation is also a limiting factor, a power shovel being effective to about 20 ft. Going deeper than this requires sheeting, and the resulting bracing extending into the basement area restricts shovel manipulation. This is particularly true on small plots. In such cases, stiff leg derricks (see p. 851) are substituted. The size of power shovel ordinarily used varies from ½ to 1¼ cu. yd. dipper capacity.

A convenient classification of power shovels is by type of motive power. Thus, there are steam shovels, gasoline shovels, electric shovels, gasoline and electric shovels, gasoline and air shovels, and Diesel shovels.

General Features.—All shovels are made up of four main parts—the mounting, the base frame, the revolving frame, and the boom-and-dipper-stick assembly.

The mounting is invariably of the crawler type consisting of a cast-steel articulated tread mounted on rollers, one or two of which are driving rollers. The latter are geared directly to the power unit or receive their power through chains and shafts. Steering is usually accomplished by disengaging either one or the other of the treads from the driving power. Most crawlers are self-cleaning. Two to four axles are used. Usually, two speeds forward and reverse are provided, ranging from ¾ to 1½ m.p.h.

The base, which rests on the axles, is a single steel casting or in some cases a riveted or welded structural-steel frame. Likewise, the revolving frame which carries the machinery and cab is a unit steel casting in the better machines. The boom-and-dipper-stick assembly is usually considered to include the structural steel "A" frame which is fastened to the revolving frame and carries a head block to which are attached the cables which support the upper end of the boom. The boom is invariably of structural steel and may be made of two parts with a space between for the passage of the dipper stick, or it may be of the box-girder type, in which case, two dipper sticks are used placed outside the boom. The latter design is effective in eliminating twisting strains and weaving.

A special boom-and-dipper arrangement is shown in Fig. 3. Whereas on other machines the dipper stick or shipper shaft, as it is often called, is placed on top of the boom, here it is placed at the center. This is claimed to give the dipper added reach and a higher dumping angle. The dipper stick is carried on large circular steel bearings which give it lateral support. The boom is unusually wide at the base to eliminate twist strains.

The dipper stick is ordinarily of wood reinforced with steel plates and varies in length from 14 to 20 ft. A typical 1¼-yd. power shovel with its boom at a 45-deg. angle and an 18-ft. dipper stick has a maximum dumping radius of 29 ft. 9 in., a clear dumping height of 19 ft. 1 in., a boom height of 20 ft. 8 in., an effective single-line pull on the dipper of 15,500 lb., and an 81-hp. engine. The shovel weighs 69,000 lb.

The dipper is ordinarily of special or alloy cast steel and ranges in capacity from ½ to 1¼ cu. yd., although dippers are built up to 15 cu. yd. on some ore stripping machines. Unfortunately, "capacity" may mean heaped, struck, or water measure, and care is, therefore, necessary in comparing makes of the same nominal capacity. In hard digging, manganese, or other alloy, steel teeth are fitted to the dipper lip. The hoisting line in most cases is connected to the dipper through a sheave and a hinged bail, but on some machines it is merely fastened to the back of the dipper by a pivoted block.

A special dipper known as a back-digger or pull-shovel is often used. Its manner of operation is evident from its name. This type of dipper is usually attached to a short stick which is hinged to the end of the shovel boom,



Fig 1 —Convertible ¾ yd shovel and crane powered by 72 hp gasoline engine

the ordinary dipper stick being removed. In some designs the tilting of the bucket is accomplished solely through this hinge, while in others the bucket itself can be tilted. The latter design (Fig. 6) is especially useful in cutting vertical cellar walls and doing trimming work generally.

Types of Shovels.—The steam shovel, the once universal type, is slowly being replaced by other types of power. It is still, however, the ideal in flexibility and ease of operation, its



Fig. 2.—Bucyrus-Erie gas + air shovel.

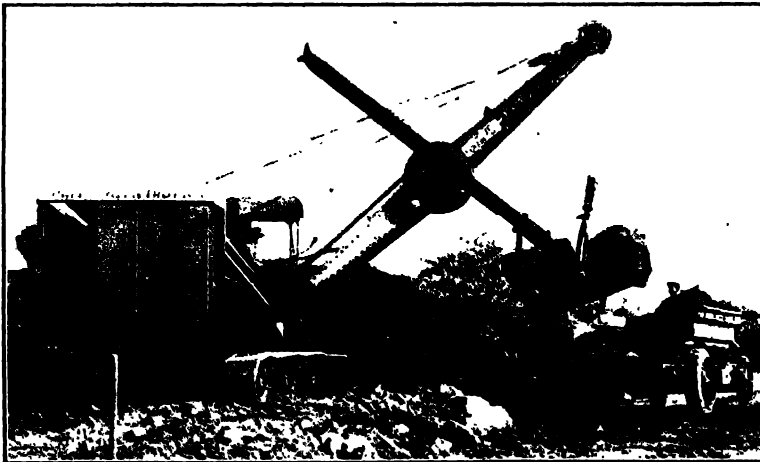


Fig. 3.—Thew 1¼-yd. gasoline shovel.

three independent throttle-controlled engines for crowding, swinging, and travel being designed to give high speeds under light loads and to stall under extreme loads. The chief disadvantages of the steam shovel center around inconvenience and dirt.

The gasoline shovel uses only one engine, and the power is applied to the various motions—crowd, swing, and travel—by means of clutches. Various devices are used to make the operation of these clutches easy, among them long levers and air or hydraulically operated pistons.

The size of engine used varies from 40 to 90 hp. for shovels from ½ to 1¼ yd. capacity. A 1-cu. yd. 90-hp. gasoline shovel with oil hydraulic control for crowd, hoist, and travel is manufactured by the Austin Machinery Corporation. A triplex plunger pump circulates the oil under a pressure of 125 lb. per sq. in., the pressure being maintained by an accumulator. Three-



Fig. 1.—A shovel in the smaller class—Bay City ½-cu. yd. with McCormick-Deering tractor engine.

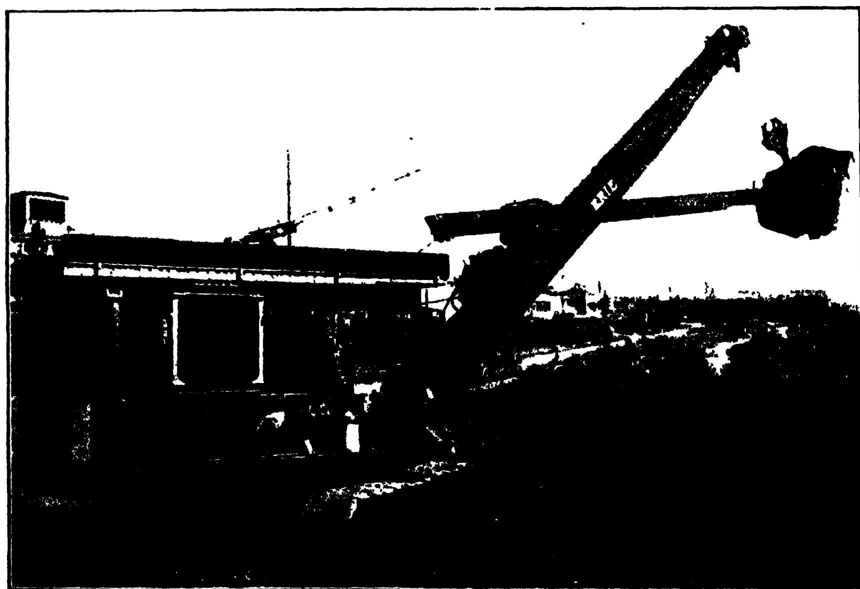


Fig. 5.—Bucyrus-Erie 1-yd. Diesel shovel.

way valves operated by a single lever control the hydraulic rams which actuate either band- or cone-type clutches.

Following the development of Diesel engines practically equal in weight per horsepower to gasoline engines, the former type of power is now offered by nearly all manufacturers. The method of operation of Diesel shovels is, of course, the same as for gasoline-powered shovels, namely, through clutches.

The gasoline and air shovel or the "gas + air" shovel, as the model manufactured by the Bucyrus-Erie Company is called, uses both gasoline and air engines. The gasoline engine is the primary power, used to operate an air compressor and to furnish power for hoisting. Both crowd and swing are accomplished by direct-connected throttle-controlled air engines running on heated compressed air at 125 lb. pressure. No clutches are used, and the operation is thus quite comparable to that of the steam shovel.

The gasoline and electric machine, such as manufactured by the Marion Steam Shovel Company, also uses independent engines. The gasoline engine drives an electric generator to make power for the electric motors—one each for the hoist, the swing, and the crowd, thus providing operation quite similar to that of a steam shovel.



Fig. 6.—Thew pull shovel with tilting dipper.

1b. Cranes.—Three types of cranes all using two- or three-drum hoists are available for application to building construction work, using either hooks or grab buckets, the latter either for excavation or for handling materials such as earth or concrete aggregates.

Practically all makes of power shovels are convertible to cranes by a simple interchange of booms and a re-reaving of the cable lines. Crane booms are of latticed structural steel in lengths varying from 35 to 50 ft., for 1- to ½-cu.-yd. buckets respectively. Representative data on one of these convertible-type cranes, of 1 cu. yd. capacity with 35-ft. boom, are as follows: With boom at 40 deg. inclination, the dumping radius is 32 ft. 11 in., the dumping height is 17 ft. 7 in., and the digging radius is 39 ft. 11 in. A 35-ft. boom has a load capacity at a 12-ft. radius of 17,600 lb.; and at 30 ft., of 6800 lb.

Locomotive cranes can be used under certain conditions, being particularly useful for placing steel on large one-story buildings. These cranes are similar in construction to crawler cranes but are mounted on railroad trucks (Fig. 8) and use booms up to 75 ft. in length. Mostly, they are operated by steam, although the trend is toward the other kinds of power. Locomotives cranes vary in weight from 45 tons in the smaller or 10-ton capacity to 90 tons for the larger or 30- to 40-ton capacity.

The third class of cranes are motor-truck-mounted units which are adaptable to practically all types of crane service. Power is taken from the motor-truck engine through chains and

gears. The rear traction mounting consists of either four or six wheels. On one make shown in Fig. 7, a removable crawler tread is provided for use in soft ground. All truck cranes have the advantage of ready and rapid portability from one job to another.

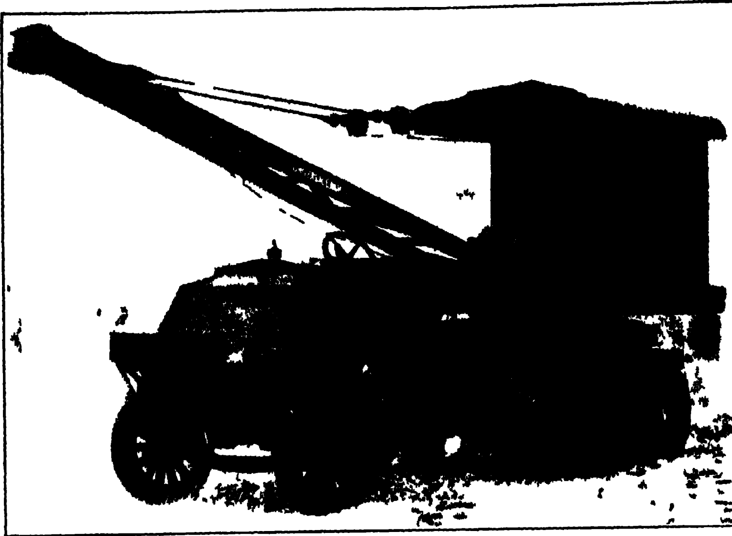


Fig. 7.—Universal truck crane equipped with removable crawlers.

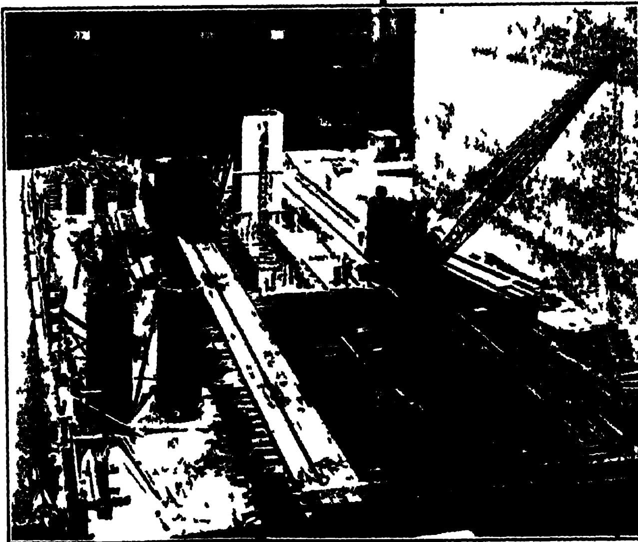


Fig. 8.—Industrial Brownhoist locomotive cranes in operation.

1c. Fixed Derricks. Stiff-leg and mast derricks operating grab buckets are often useful in excavating foundation sites that are too congested with bracing to permit crawler-shovel operation. Such derricks are indispensable when rock has to be excavated, metal skips

are used when the rock is well broken, while large pieces of rock are removed by chain slings. Further data on derricks are given on p. 895.

1d. Grab Buckets.—The two principal types of grab or automatic buckets used in building excavation are the clamshell and the orange peel. The orange peel is ordinarily used as a digging bucket, while the clamshell is made in various types suitable both for handling loose materials and for digging. Numerous other types of buckets, particularly in bottom dump and tilting designs, are used for handling work, particularly in depositing wet concrete.

Clamshell Bucket.—Clamshell buckets (Figs. 9 and 10) consist of two curved jaws which when closed form half of a short cylinder. Two sets of steel arms connect these jaws to the head casting. Very little change has been made in the shape of the bowl since such automatic buckets were patented in 1848, but the closing mechanisms are of various types. The three outstanding types of closing mechanisms may be classified as the power-wheel, the sheave or

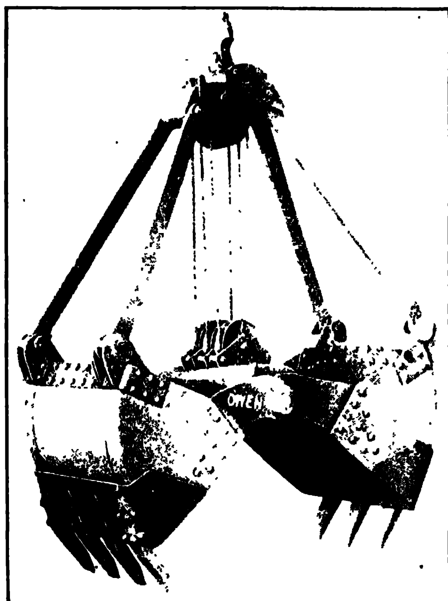


Fig. 9.—Owen clamshell bucket, sheave closing type.

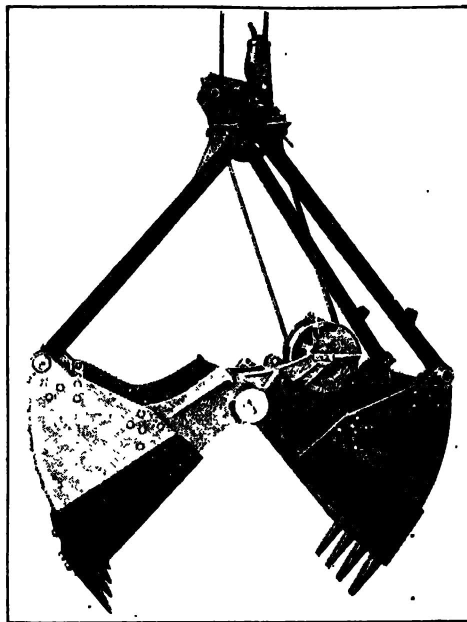


Fig. 10.—Blaw-Knox clamshell bucket—lever-arm closing type.

block-and-tackle, and the lever-arm. In most buckets used in building excavation work two lines are necessary for operation—a closing line and a holding line, each acting as its name implies, and each requiring a drum on the hoist.

With a power-wheel mechanism the operation of closing the bucket is accomplished by winding the closing line around a large-diameter pulley wheel mounted on an axle that forms part of the hinge of the bucket. Attached to this axle on each side of the wheel is one end of a chain or cable, the other ends being fastened to the top of the bucket. This type of bucket has a large pick-up capacity in loose soft material, operates very rapidly, and requires little headroom. When heavy digging is encountered, counterweights may be added between the spokes of the power wheel.

The sheave type of closing mechanism gives a more powerful closing action than the power-wheel type. Movable sheaves replace the power wheel, and stationary sheaves are placed in the head of the bucket. Cable reaving between these two sheaves will develop closing ratios as high as 10:1. While this type of closing mechanism is suitable for digging some types of material, a combination of this type with a lever arm produces a greater mechanical advantage and exerts a correspondingly greater force. In this latter type of closing mechanism the lower sheaves are attached to one end of a lever instead of being placed on the hinge; the other end of the lever is attached to the hinge. This bucket requires a smaller number of sheaves than does the block-and-tackle type and exerts a more effective closing power as a result of the long travel of the sheave in the lever arm.

Orange-peel Buckets.—In the orange-peel bucket, multiple blades replace the two curved jaws of the clamshell. The power-wheel and block-and-tackle closing methods are found on the orange peel, while the lever arm has so far been adapted only to clamshell buckets. Three or four blades are usual. The orange-peel bucket has a powerful digging purchase and is heavier, capacity for capacity, than a clamshell—a 1-yd. clamshell weighing about 3000 lb. Orange-peel buckets are built in a wide range of sizes. The smallest clamshell is a ½-yd. bucket, while special "dwarf" orange peels for removing material from steel casings for foundation piling are built to carry as little as 100 cu. in. of material.

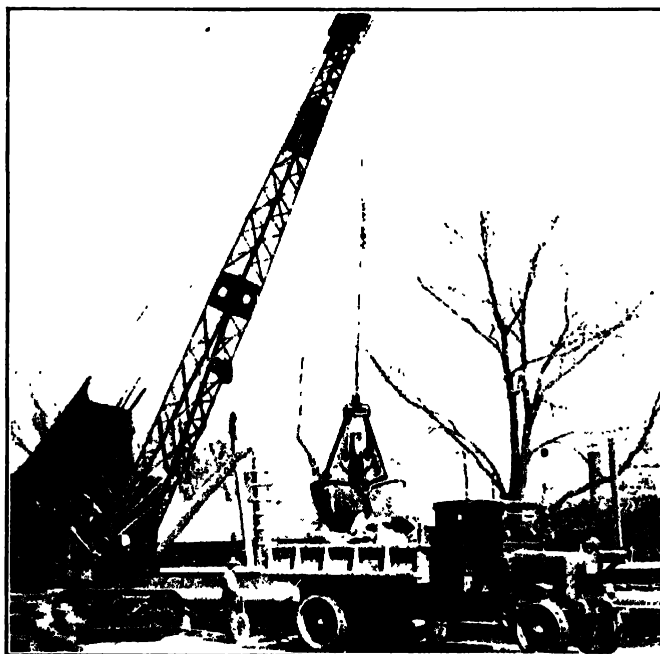


FIG. 11.—Hayward orange peel bucket—power-wheel closing type.

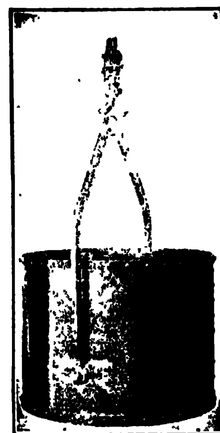


FIG. 12.—Round self-tilting bucket.

the accompanying tables are give of the sizes and dimensions of both orange peel and clamshell buckets

CLAMSHELL BUCKETS FOR EXCAVATING OR DREDGING

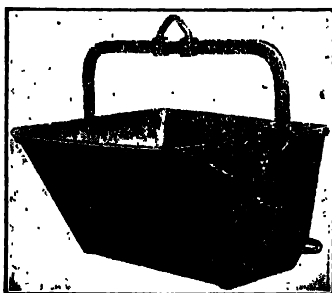
Owen Bucket Company

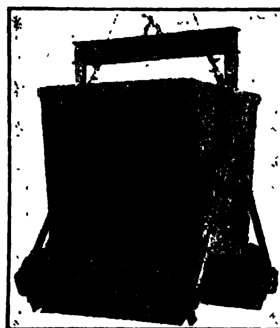
Capacity, cubic yards	Height, open (including arms)	Bucket length, open	Height, closed (including arms)	Bucket length, closed	Bucket width	Weights (without counter weight or teeth), pounds
¼	5 ft. 8 in.	5 ft. 0 in.	4 ft. 6 in.	4 ft. 2 in.	2 ft. 1 in.	1,100
½	7 ft. 4 in.	6 ft. 1 in.	5 ft. 9 in.	5 ft. 6 in.	2 ft. 8 in.	2,500
¾	7 ft. 10 in.	6 ft. 4 in.	6 ft. 2 in.	5 ft. 10 in.	3 ft. 2 in.	3,400
1	8 ft. 7 in.	7 ft.	6 ft. 10 in.	6 ft. 6 in.	3 ft. 2 in.	3,565
1¼	8 ft. 10 in.	7 ft. 7 in.	6 ft. 11 in.	7 ft. 1 in.	3 ft. 2 in.	3,775
2	10 ft. 1 in.	9 ft. 4 in.	8 ft. 1 in.	7 ft. 9 in.	4 ft. 1 in.	4,550

ORANGE-PEEL BUCKETS
Hayward Company

Capacity	Diameter, closed	Height, closed (including arms)	Diameter, open	Height, open (including arms)	Weight, pounds
100 cu. in.	10 in.	1 ft. 6 in.	11½ in.	1 ft. 8 in.	35
300 cu. in.	1 ft. 1 in.	1 ft. 8 in.	1 ft. 3 in.	1 ft. 11 in.	45
1 cu. ft.	1 ft. 10 in.	3 ft. 1 in.	2 ft. 2 in.	3 ft. 6 in.	210
5 cu. ft.	3 ft. 2 in.	4 ft. 9 in.	3 ft. 11 in.	5 ft. 3 in.	1,000
15 cu. ft.	4 ft. 7 in.	6 ft. 6 in.	5 ft. 6 in.	7 ft. 4 in.	2,350
1 cu. yd.	5 ft. 8 in.	8 ft.	6 ft. 10 in.	9 ft.	4,400
1¼ cu. yd.	6 ft.	8 ft. 3 in.	7 ft. 3 in.	9 ft. 3 in.	4,800
1½ cu. yd.	6 ft. 4 in.	8 ft. 5 in.	7 ft. 8 in.	9 ft. 6 in.	5,350

1e. Handling Buckets.—Steel buckets used for handling materials are of many different sizes and shapes. They are classified according to the manner in which they discharge, *i.e.*, tilting or bottom dump. The tilting bucket is hung by a heavy bail hinged to the sides of the bucket which is held in the upright position by a catch. The bail is fastened a little above the center of gravity of the empty bucket so that little effort is required to dump the bucket, and it automatically returns to its upright, locked position. These buckets may be either round tubs or of the shape shown in Fig. 13. Together with the shallow, box-shaped skip they are used for handling rocks where the contents are discharged to waiting trucks or loading hoppers.


FIG. 13.—Tilting bucket.


FIG. 14.—Bottom-dump bucket.

The bottom-dump bucket (Fig. 14) discharges through doors in the bottom. It ordinarily operates with two hoist lines the same as a clamshell or orange peel. The sizes of the bucket and methods of opening vary with different manufacturers. In general, the bottom dump is square, and where the bucket is not equipped with two-line operation a system of levers is provided to be actuated by a man stationed at the point of unloading.

1f. Plows, Picks, Shovels, etc.—Little mention need be made of such tools as plows, picks, and shovels, inasmuch as their field of usefulness is well defined and understood. In spite of the great increase in mechanical methods of excavation, the pick and the shovel are still most valuable tools. All such tools should be selected with their wearing ability in mind. Shovels, particularly, require considerable care in selection because of the many types available for different purposes. One classification of shovels is made according to the shape of the cutting edge, the sharp-pointed shovel being used for digging in hard ground, whereas a square-pointed one is needed for loose materials. A simplification program has been worked out by the various

manufacturers and the U. S. Department of Commerce so that the ordering of shovels for various purposes is not the task it once was. Besides being classified according to shape and size, shovels are also available in different grades of steel—ordinary carbon steel, heat-treated carbon steel, and various alloy steels.

1g. Scrapers.—Scrapers, used in building excavation, are of two general types—drags or slips, and wheeled scrapers. In addition to the ordinary slip shown in Fig. 15, there are the fresno and the rotary fresno, as shown in Fig. 17, for specialized work.

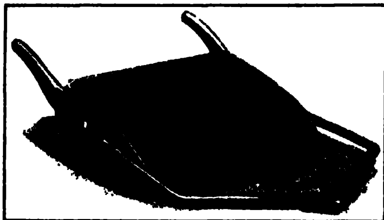


Fig. 15.—Drag scraper.

Drag Scrapers.—The slip or drag scraper is made of steel plate and sometimes provided with an extra bottom or with runners and has a heavy bail hinged to the sides as a means of attaching a team of horses. Wooden handles, fastened to the sides, enable the operator to guide and trip the scoop. This type of scraper is advantageous in places where heavier machinery cannot be employed and where the haul is not over 200 ft. The fresno is used in connection with a plough and can more easily be handled by one man than can an ordinary drag scraper. The fresno fills with dirt and, in addition, pushes considerable dirt in front of it. The runners on the fresno are adjustable so that it can be used for leveling land where only a thin coating of earth is to be removed. The rotary fresno is similar in construction but is larger and designed

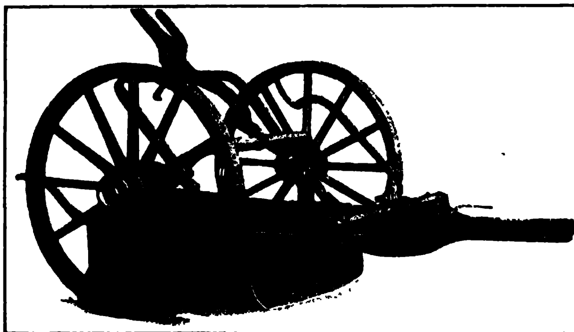


Fig. 16.—Wheeled scraper in position to load, Western Wheeled Scraper Co., Aurora, Ill.

for operation with a small fast-moving tractor. It is operated by the tractor driver. The pan turns completely over and can be dumped, righted, and set for loading without stopping the tractor. Drag scrapers are available in 3½, 4½, and 5½ cu. ft. capacity, while fresnos are available in sizes cutting from 2½ to 5 ft. deep. Three or four animals are required for the larger sizes, while two animals are usual for those fresnos cutting from 2½ to 3½ ft. A rotary fresno cuts a width of 5 ft. and a depth of approximately 2 ft. All of these machines work most efficiently on short hauls.

Wheeled Scrapers.—The wheeled scraper (Fig. 16) consists of a steel box, with one open side, suspended from an axle which is supported by wide tread wheels, about 40 in. in diameter. Attached to the box are levers which enable the operator to raise, lower, or dump the scrapers while in motion. Although ordinarily operated by a team, a special hitch adapts the wheeler

to small tractor operation. The chief usefulness of the wheeled scraper commences about where that of the drag scraper ceases, and its limit of hauls is about 1000 ft. Wheeled scrapers are available in capacities from 7 to 16 cu. ft. The 7-cu.-ft. size has a box 32 in. wide, 32 in. long, and 10¼ in. deep, and the 14-cu.-ft. size has a box 38 in. wide, 41 in. long, and 13½ in. deep. For long hauls of material loose enough to spill over the open end, there are available automatic end gates which will retain the material in the box. These end gates operate with the raising and lowering of the box.

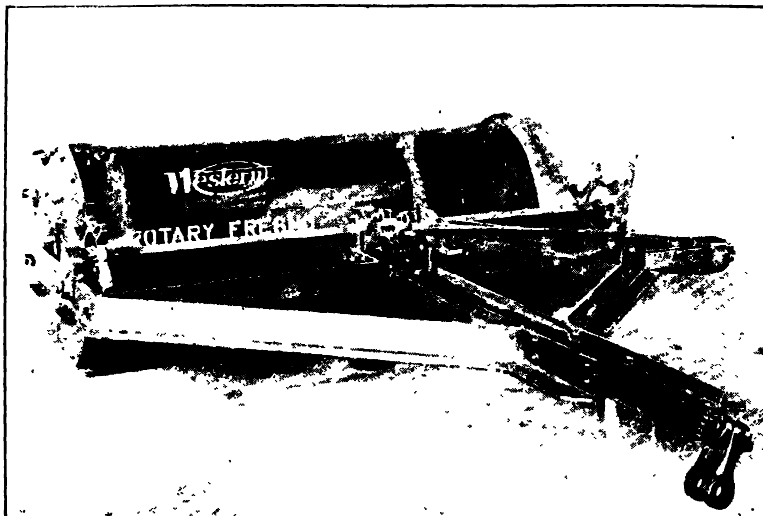


Fig. 17.—Rotary Fresno, Western Wheeled Scraper Company.

2. Rock Excavating Equipment.—In rock excavation, two general methods are available for breaking the rock into sizes which can be handled by hand or by the mechanical means available. These are explosives and the plug and feather. The art of the use of explosives has developed to such an extent in the hands of licensed explosives men—who are usually required by law to handle the explosives—that it is, to all practical purposes, the only means employed to break up rock. Even in crowded quarters, the use of small charges together with mats of hemp or wire rope to eliminate flying pieces of rock is more satisfactory and economical than the plug-and-feather method.

2a. Explosives.—Explosives, of course, require care in handling and in storage. Moisture and temperature changes are the main things to be avoided in storage. Three types of magazines are approved by explosive manufacturers in which to store explosives—soft-brick magazines, sand-filled wall magazines, and portable iron magazines. Concrete is not safe because of the danger from flying missiles in the event of an explosion. Magazine floors should not rest on the ground. Proper and sufficient ventilation is absolutely necessary to insure dryness and uniform temperature. Separate magazines should always be provided for blasting caps and accessories. Distances of magazines from other buildings are usually governed by law, but otherwise the American Table of Distances should govern. This table can be secured from any manufacturer of explosives. In fact, all questions of doubt should be referred to these companies, all of whom maintain service organizations of high caliber.

Explosives are divided into two classes, dependent upon the force exerted—*i.e.*, black powders, which are weakest, and dynamites (nitroglycerine, nitrate of ammonia, gelatine, or nitrostarch types), which are strongest.

Black Powders.—Black powders are slow burning and consist of 65 to 75% potassium nitrate, 15 to 20% charcoal, and 10 to 15% sulphur. They come in kegs holding 25 lb. or more.

Because of difficulty in handling, they must be carefully poured through a funnel into the hole or else made up in brown-paper cartridges and shoved into the hole with a stick. Black powders are not so extensively used as are the dynamites.

The size of the powder grain affects the rapidity of burning, the smaller grains being the quicker burning. A good powder is dark gray or slate color. When burned on a sheet of white paper, it should leave no residue.

Black powder may be fired by a battery or by a fuse which is a thin train of powder surrounded by tape. Different types of fuse, which burn at a known rate of from 35 to 40 sec. per ft. are available for dry work, damp work, wet work, or under-water work. When using a battery, electric squibs, which are heavy paper shells filled with a quick flashing powder, are placed in the center of the black powder and shoot out a small flame which ignites the charge.

Dynamites.—Although dynamite is in common usage synonymous with all high explosives, it is, as a matter of fact, only one of the several types available. Straight dynamite contains nitroglycerine, wood meal, or other combustible material, and sodium nitrate. It is the most sensitive of the dynamites, very quick, and obtainable in strengths (based on percentage of

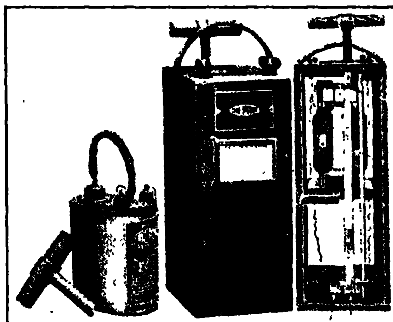


FIG. 18.—Du Pont blasting machines. Pocket size machine on left has capacity of 1 to 3 electric blasting caps. Machine on the right has capacity of 50 caps.

nitroglycerine) up to 60%. Ammonia dynamite is similar to straight dynamite with the addition of ammonium nitrate. Straight gelatines are distinguished by their plasticity, imperviousness to water, and the comparative freedom of their explosion product from noxious fumes. They contain nitroglycerine, sodium nitrate, wood pulp, or other combustible material, and nitrocotton. Ammonia gelatines are the same with the addition of ammonium nitrate. Blasting gelatine, which consists of nitroglycerine and nitrocotton, is a tough, elastic, jelly-like mass and is the strongest and most water-resisting of all explosives. It is particularly useful for hard rock and large holes.

"Dynamite" is commonly packed in paper cartridges from 6 to 16 in. long and ⅞ to 2 in. in diameter and is shipped in boxes of 25 to 50 lb. each. A strength of 40% is most commonly employed.

Blasting Accessories.—All explosives, if they are to be fired with full strength, require the use of certain accessories. The cost of these accessories is so small in comparison with the explosives that the best grade obtainable should always be used.

Strong detonators assure the most efficient use of the explosives. Detonators are of two types—electric blasting caps and blasting caps used with fuse. The fuse has been described previously. Blasting caps are small drawn copper cylinders, closed at one end, the "business end," and loaded with a small charge of very sensitive and violent explosive. They are packed in tin boxes each containing 100.

Many kinds of blasting can be accomplished only by electricity such as submarine and wet blasting, and all kinds can be performed more safely, quickly, and conveniently by this method. An important characteristic is that several charges can be fired simultaneously. Electric

blasting caps are also small copper cylinders. They contain fulminate of mercury at the business end in which is embedded a copper-wire circuit held in place by an asphalt plug inserted in the other end. Wires extend out of the caps and to the top of the hole. Stock wire lengths vary in 2-ft. increments from 4 to 20 ft.

Blasting Machines.—Blasting machines are used to generate current for firing blasts by electricity. While electric power or lighting circuits can be used where available with proper voltage and amperage, blasting machines are the more usual. They are in effect small portable dynamos in which the armature is rotated by the downward thrust of a rack bar (Fig. 18). The machines should be used with electric blasting caps connected in series only and never in multiple or parallel. They are available in sizes suitable for firing from 3 to 150 electric blasting caps at one time. The best way to operate a blasting machine is to "try to knock the bottom out of the box." Also, two or three short preliminary strokes in a pumping action tend to strengthen the magnetic field and get the maximum current from the final stroke.

The small pocket blasting machine, also shown in Fig. 18, is operated differently from the other machines. This machine is grasped in the palm of the left hand, and a quick turn of the firing handle with the right hand generates the current.

2b. Rock Drills.—Drilling rock may be carried on by hand or by machine drills. Hand drilling, unless the number of holes to be drilled is small or the work carried on away from sources of steam or air, is not much used in building construction. The smaller types of machine drills are made light enough to be readily portable and easily handled by one man and these are the types most generally applicable to building foundation excavation. In the larger sizes, these machines may be mounted on tripods and adjusted to drill horizontally, at an angle, or vertically. Air is the most universally used power. Electric drills have to be too large for a comparable amount of work, and gasoline operated drills have so far not been a success. The machines described below are all air drills.

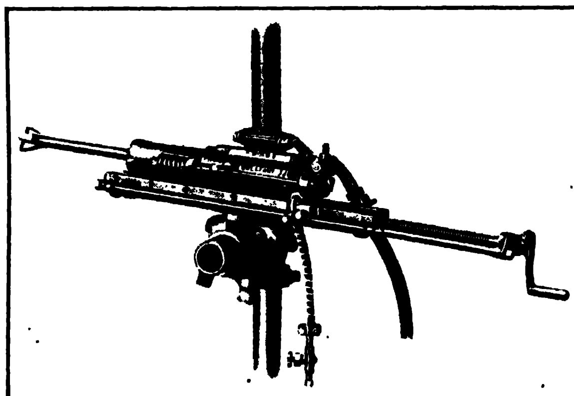


Fig. 19.—Sullivan T-3 water drifter.

In hand drilling, a hammer weighing 4 or 5 lb. is ordinarily used, although where one man holds the drill and another uses the hammer, the weight is sometimes increased to 10 lb. Successful hand drilling is usually a product of skill and judgment on the part of the striker to know how to strike the drill in order to keep the bottom of a hole clear so that the drill is operated on solid rock and not on loose fragments. A drill of ¾ to ⅞ in. in diameter with a chisel bit is most commonly used, although star and rose bits are useful when holes are to be drilled in cement or brick work for the placing of expansion bolts, etc.

Machine Drills.—Machine-operated drills are invariably of the hammer type—that is, the drill steel is entirely separate from the piston, the latter striking the drill steel direct or

transmitting the blow through a striking block. Piston drills in which the drill steel acts as a part of the piston are practically extinct.

Except in special communities like New York City where very hard rock is encountered close to the surface, the hand-held type of hammer drill fills every requirement. Hammer drills are made by a number of manufacturers, the principal difference in design being in the valve control and in the means of rotating the drill steel. In general, a hammer drill consists of a casing which contains all the moving parts, having a handle at one end and a "steel holder" or chuck for the drill steel at the other. The blow is delivered by a light piston with a short stroke under pressures of 80 to 100 lb. per sq. in. The piston may either strike the end of the steel direct, or a striking pin or block may be interposed. All hammer drills now employed utilize a self-rotating mechanism for the drill steel. Also, all drills are automatically lubricated. One-man hammer drills vary in weight from 30 to 50 lb. and drill holes from 8 to 12 ft. deep. For deeper holes, or for holes placed horizontally or at an angle, tripod mountings for the hand-held type of drills are available.

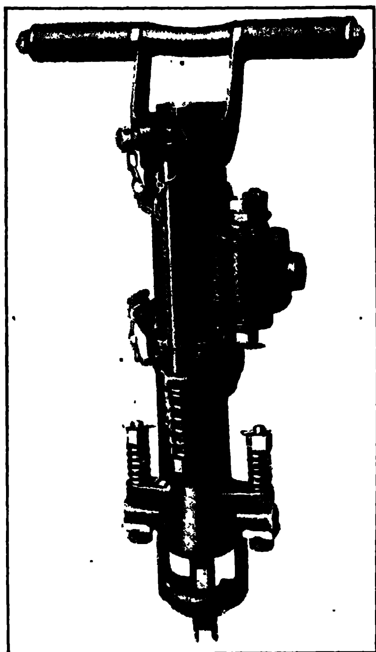


Fig. 20.—Sullivan hollow-piston rotator.

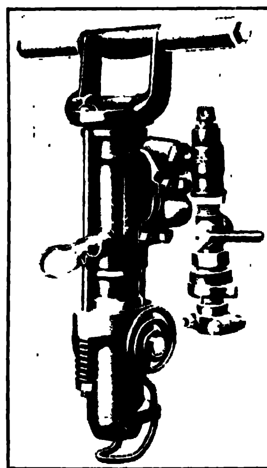


Fig. 21.—Ingersoll-Rand jackhammer air drill.

The main classification of the hammer drill from an operating standpoint is made with regard to the method utilized for ejecting the cuttings from the hole.

Where no difficulty is encountered in cleaning the hole, as in shallow drilling or in very hard rock, a solid-piston design is adequate. The chief advantage of the solid-piston type is its economy of air. But where the hole must be constantly cleaned, a piston with a jet of live air or steam discharging through a hole running from end to end of the piston and into a hollow drill steel is better. On some hammers a special air tube can be provided which will be more effective than a straight hollow-piston type for down holes in damp or sticky ground. A variation in this design provides for holding the piston at the rear end of the cylinder while the jet of air is thrown directly into the forward end of the cylinder and thus into the hollow drill steel. In another type the air tube is replaced by a steam tube, but this design is not recommended for holes deeper than 5 or 6 ft.; its main advantage lies in the fact that it can be used advantageously in connection with a steam shovel when air is not available.

For drifting and drilling at an angle, machines utilizing a combined air and water jet do effective hole-cleaning work. Finally, when drilling soft and medium-hard rock, a machine with a light, rapid stroke gives better results than a heavier machine. Using a water tube, it is necessary to have pipe-line pressure or a pressure tank available.

A machine known as a calyx core drill is often used to make borings for elevator plungers. It removes the material in the shape of cores 6 to 10 in. in diameter, as compared with other drills that remove the rock as cuttings.

Jack-hammer, Hand-held Drills

Ingersoll Rand Company

(The "BCR, DCR and DDR" drills can be converted to water machines by adding a few parts. They can be operated by either compressed air or steam, but any rock drill operated by steam is only about 50 % as efficient as when operated by compressed air.)

Data	BAR33	BCR430	DCR13	DDR13
Bore of hammer cylinder	2⅜ in.	2¼ in.	2⅜ in.	2⅝ in.
Length of drill	15¼ in.	20¾	21¼	24½
Size of hose	½ in.	¾	¾	¾
Weight	21½ lb.	47 lb.	56 lb.	73 lb.
Type of service	For light drilling in soft or medium rock to a depth of 4 ft.	For the greater majority of hammer drill work to depths of 9 ft. in hard rock	For shaft sinking in average rock	For the heaviest and roughest hammer drill service to depths of over 12 ft. in the hardest rock

Rotator Hammer Drills—Hand Held

Sullivan Machinery Company

Data	L-7	L-7	DP-331	L-5	T-3
	Solid or hollow-piston rotator	Air or water-tube rotator	Steam-tube rotator	Medium-weight hollow-piston rotator	Water drifter
Depth of hole	12 ft.	12 ft.	6 ft.	12 to 18 ft.	12 to 25 ft.
Weight	45 lb.	47 lb.	50 lb.	75 lb.	156 lb.
Size of hose	¾ in.	¾ in.	¾ in.	1 in.	1 in.

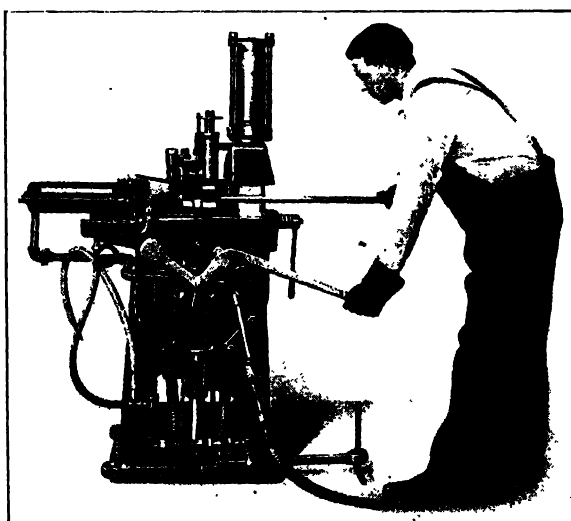


Fig. 22.—Air operated drill steel sharpener, Sullivan Mchy. Company.

Drill Steel and Bits.—Since high-grade alloy drill steel requires low heat and great care in forging, a good carbon steel is almost universally used. Also, it is hard to distinguish between an alloy and a carbon steel by appearance alone, and where both are on the job difficulties in storage are encountered. Hollow-steel bits are more difficult to temper and dress than are solid bits. The nature of rock and size of hole should govern the grade of steel chosen. Octagon, hexagon, and round are the shapes commonly used, the first two being in special favor, since they offer more grip to the chuck and are, therefore, rotated more easily. Steel may be obtained in lengths from 2 to 25 or 30 ft.

Drills may be forged, dressed, and tempered either by hand or by special machine. Portable sharpeners (Fig. 22) and oil or gas furnaces for heating are available. The machine sharpeners do all upsetting and swaging to uniform dimensions. Small steel furnaces will hold about a dozen 1¼-in. bits. The light-weight sharpener weighs about 1100 lb., and the furnace about 1000 lb.

The design of the bit will play an important part in the cutting efficiency. The double-taper bit is the most important development of recent years in drill steel. It keeps the hole smooth, increases speed, reduces breakage, and keeps the hole to gage. The bits shown in Fig. 23 are used in American practice with the cross-bit the most common. Information on the type of bit to be used on various classes of drilling service may be obtained from the manufacturers of rock-drill equipment.

2c. Other Pneumatic Excavating Tools.—Pneumatic clay spaders and concrete breakers can be used to unusual advantage where hard digging is encountered and speed is desired. Both operate similarly to the pneumatic hammers. The clay spader (Fig. 24) is particularly useful in excavating caissons where the ground is not sufficiently hard to be drilled and yet is too hard to be handled readily by hand pick and shovel methods. The tools weigh from 25 to 50 lb. In addition to the spade, asphalt cutters, chisels, and other tools may be inserted. The concrete breaker or demolition tool is especially useful in removing old concrete from excavations and may be employed to drill occasional blast holes in rock by using a hollow-drill steel. It weighs about 75 lb.

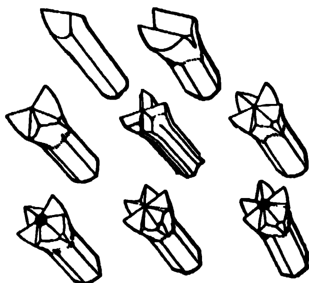


Fig. 23.—Drill bits, Ingersoll-Rand Co., N. Y.

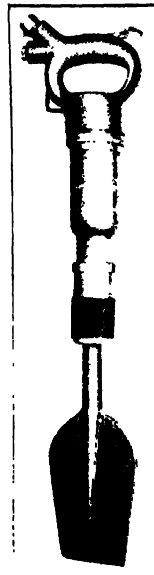


Fig. 24. Pneumatic clay spader, Chicago Pneumatic Tool Company.

MATERIAL TRANSPORTING EQUIPMENT

By Waldo G. Bowman

For the transportation of such materials as earth, rock, sand, cement, and wet concrete, the wheelbarrow, the wagon or trailer, the motor truck, and the belt conveyor are the outstanding pieces of equipment.

3. Wheelbarrows.—Wheelbarrows for construction work are preferably of all-steel construction. The box of such barrows is made in a variety of shapes and sizes to meet different requirements. The efficient use of wheelbarrows is limited to about 150-ft. runs in general.

4. Wagons.—The type of wagon in most general use for building construction purposes has a drop bottom. Trailers are differentiated from wagons largely by the fact that they are fitted for motor-truck or tractor attachment. The slat-bottom wagon also is sometimes used.

Drop-bottom wagons are made in various sizes ranging from 1 to 5 cu. yd. capacity with 1 to 2½ cu. yd. wagons being most common, the size depending on the conditions of haul and the loading arrangements. This wagon is



Fig. 25.—Crawler trailer wagon with Caterpillar tractor.

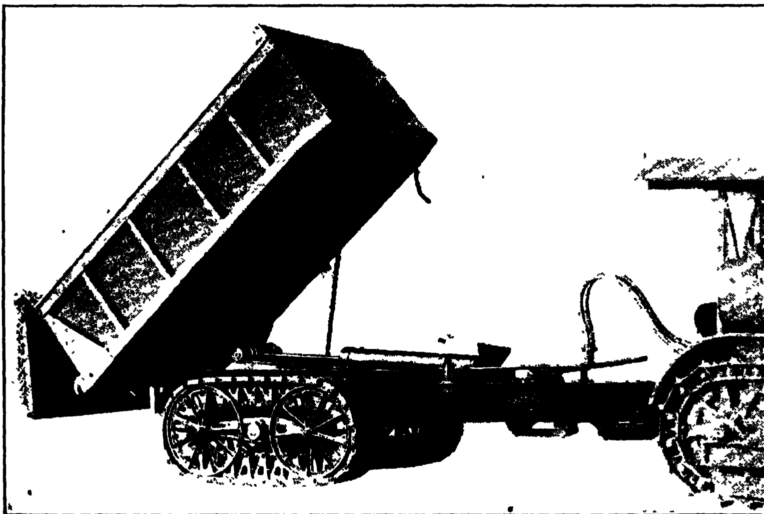


Fig. 26.—Crawler trailer with rear dump operated by tractor driver, Athey Company.

built in the shape of a rectangular box with sloping ends and sideboards, the bottom consisting of two doors which open downward. One side of each door is hinged to the sideboard, and the other is connected by a chain through pulleys to a winding drum under the driver's seat. The driver may thus release the load and then bring the doors back to closed position by a ratchet lever without stopping his team. Bottom-dump wagons are usually equipped with heavy tires of broad tread to enable them to be used on fairly soft ground.

For efficient service on all kinds of hauls, the crawler-mounted trailer either of the bottom-dump (Fig. 25) or end-dump type (Fig. 26) is best. In combination with a crawler tractor both give unusually good results. Because of its ease of handling on soft ground, the crawler trailer can be built in large sizes, some models having capacities of from 7 to 15 cu. yd. On these trailers there are two sets of bottom-dump doors, one in front and one back of the axle, and these are operated similarly to the bottom-dump doors of other wagons.

5. Motor Trucks and Tractors.—Motor trucks, for speed and long hauls, and crawler-mounted tractors, for hard pulling and heavy operation, are available in a variety of sizes. Motor-truck capacities range from 1 to 10 tons with the 1-, 3-, and 5-ton capacities being most adaptable to building construction. Steel bodies of the rear-dump type are the most usual on motor trucks, the dumping being accomplished by a power hoist which raises the front part of the body. Use of light-weight trucks is worthy of careful consideration on small operations where the cost of upkeep of larger trucks would not be warranted. These are available in sizes as small as any contractor would desire.

The crawler tractor, operated by gasoline or Diesel engines, and ranging in size from the small Fordson to huge 100 hp. models, are supplanting animals on the majority of building exca-

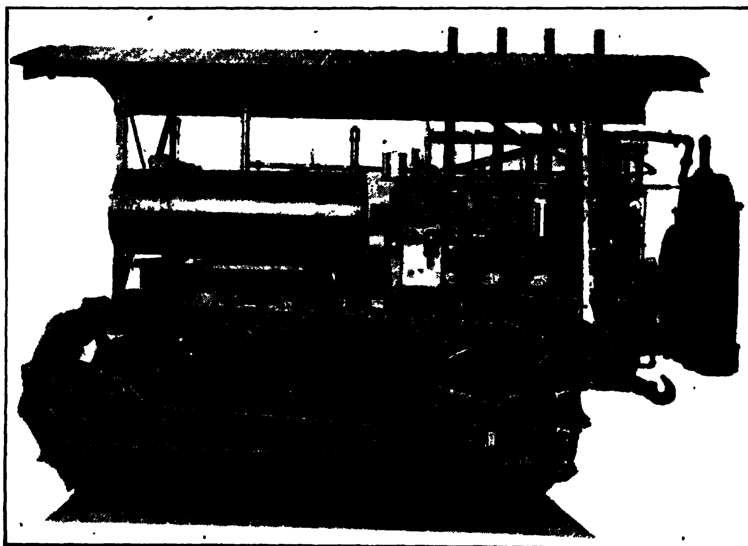


Fig. 27.—Caterpillar tractor powered with Atlas-Imperial Diesel engine.

vation jobs. On a job where the material can be loaded in the hole, a crawler tractor and a trailer will be found most efficient units. If access to the excavation is not possible, motor trucks loaded at the edge of the site by grab buckets operated by derricks or cranes will be found advantageous.

6. Belt Conveyors.—The belt conveyor as a piece of transportation equipment on the building construction job is rapidly making a name for itself. Used only intermittently several years ago, its adoption has become general for transporting earth and wet concrete (Figs. 29 and 30). Its usefulness in moving sacks of cement from the ground to the concrete-mixer platform has long been recognized.

Belt conveyors are of two types, portable and stationary. The portable conveyor is, of course, limited in length but has been built as long as 100 ft. Operation may be either by electric motor or gasoline engine. Belts are usually four-ply with a thin rubber covering on one side. Common widths of belts are 18, 24, 36, and 48 in. Belt carriers or idlers (Fig. 28) consist of three or more roller- or ball-bearing-mounted rolls arranged in the shape of a trough.

Stationary belt-conveyor installations are generally the result of a special design made for a particular job. On such installations discharge points may be located at will, and, all in all, the layout can be made as flexible as desired. In such cases, however, a belt-conveyor manufacturer should be specially consulted.

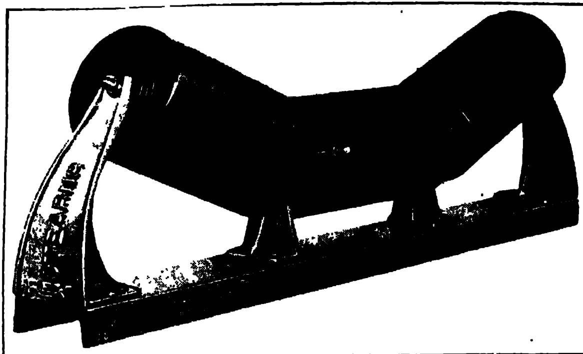


FIG. 28.—A belt conveyor carrier.

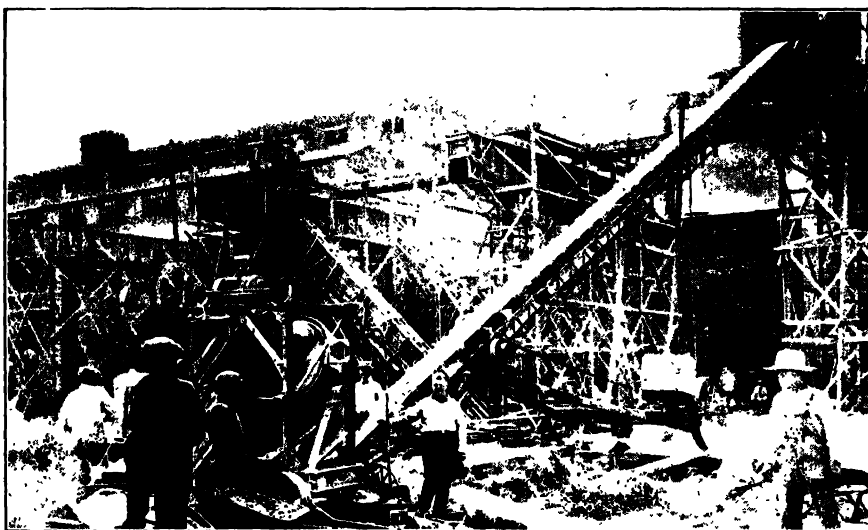


FIG. 29.—Barber-Greene belt conveyor transporting mixed concrete.

CAPACITIES OF BELT CONVEYOR USING THREE-PULLEY CARRIERS
Jeffrey Manufacturing Company

Width of belt, inches	Cross section of load, square feet	Weight of material, in pounds per cubic foot				
		25	50	75	100	125
		Tons per hour at 100 ft. per min.				
14	0.114	8.6	17.2	25.8	34.4	43.0
16	0.149	11.2	22.4	33.6	44.8	56.0
18	0.189	14.2	28.4	42.6	56.8	71.0
20	0.233	17.5	35.0	52.5	70.0	87.5
42	1.029	77.2	154.4	231.6	308.8	386.0
48	1.344	100.8	201.6	302.4	403.2	504.0

In addition to the portable belt conveyors, portable bucket loaders will be found of advantage in loading materials such as sand, gravel, and crushed stone into trucks and bins. As a general rule, the same companies manufacture bucket loaders as manufacture portable belt conveyors. From them can be secured opinions as to the suitability of each machine for a particular set of conditions.

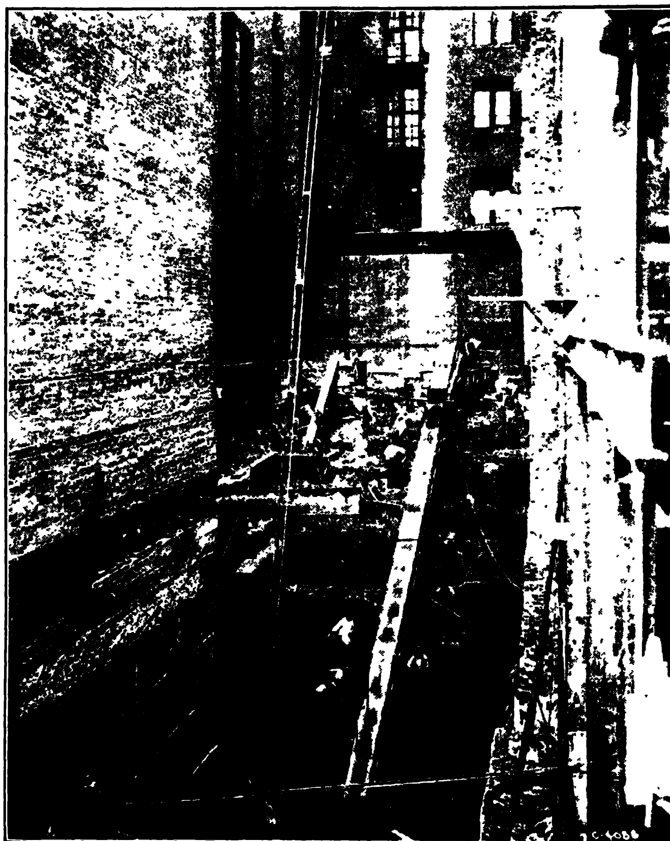


FIG. 30.—Belt conveyor removing earth excavation, Chain Belt Co.

PILING AND PILE-DRIVING EQUIPMENT

BY WALDO G. BOWMAN

7. Sheet Piling.—Sheet piling, made either of planks about 2 × 12 in. in size or of steel shapes, is driven before the excavation is begun and generally below the grade of the final excavation. Its functions are to prevent leakage of water or of soft materials such as quicksand and to withstand the lateral pressure of adjacent ground. In some cases, where a permanent retaining wall is advisable, steel sheet piling may be left in the ground and suitably anchored.

7a. Wood Sheet Piling.—When timber piling is used, the planks are driven close together and, to secure water tightness, are made double and triple lapped. The joints in use are tongue and groove or grooves cut in each side of the plank with a tongue driven separately.

What is known as the Wakefield pile (Fig. 31) consists of three planks bolted together to form a tongue on one side and a groove on the other. This gives practically water-tight construction, but as the planks are driven as a unit, the resistance to driving is considerable. By careful selection and grading of the center plank, a good joint can be secured. Three advantages are claimed for this type of piling, namely, (1) knots, cross-grains, and other defects can be seen, though it is unlikely that these defects would come at the same point of the pile; (2) there is no waste in forming the tongue and groove, and there is less tendency to buckle or warp before driving; (3) only one side of each pile is sharpened, the long edge being placed next to the last pile driven, which crowds the new pile against the old one and helps to make a tight joint.

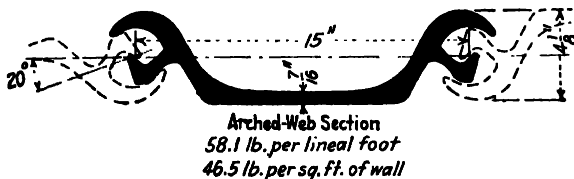

Fig. 31.—Wakefield wood sheet piling.

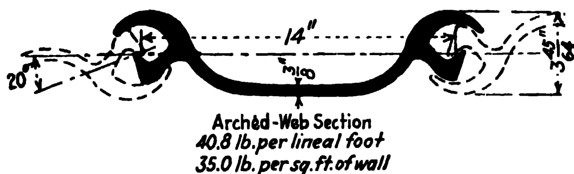
7b. Steel Sheet Piling.—Steel sheet piling has rapidly come into extended use. While the first cost is higher than that of wood, its life is longer, and the pile is easier to drive. Also, whereas steel sheet piling may be used several times, timber piling will not survive usually over one or two drivings.

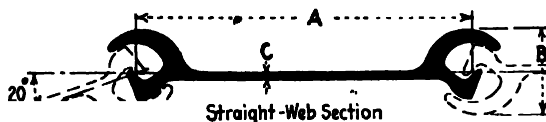
Steel sheet piling is made by a number of manufacturers, each making special claims for its own product, such as interlocking features, strength as based on the shape of the cross-section, and ability to form offsets and to turn corners. Steel sheet piling is made in straight-web and arched-web types. Taper piles are available to make final closure of a piling wall, since most walls driven one pile at a time lose distance at the bottom.

Lackawanna Steel Sheet Piling

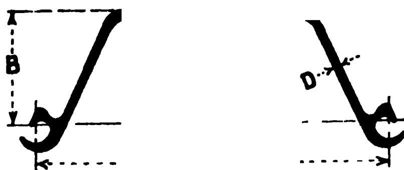
Bethlehem Steel Company







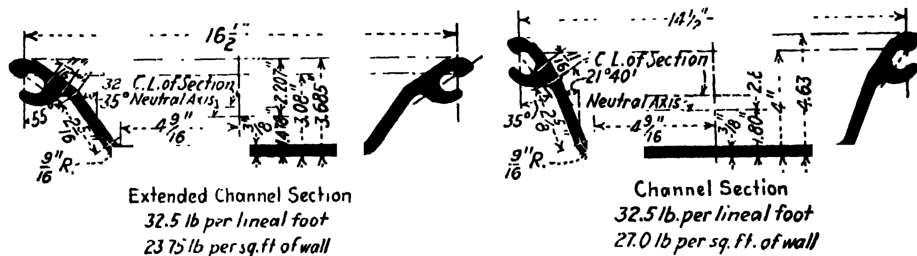
Section number	Weight per lineal foot, pounds,	Weight per square foot, of wall, pounds	A	B	C
SP 15	42.6	34.1	15 in.	3 7/8 in.	3/8 in.
SP 12b	40.9	38.5	12 3/4 in.	3 45/64 in.	1/2 in.
SP 12	37.2	35.0	12 3/4 in.	3 45/64 in.	3/8 in.
SP 8	14.7	20.8	8 1/2 in.	2 1/2 in.	13/64 in.
SP 8a	17.8	25.1	8 1/2 in.	2 1/2 in.	3/8 in.



Deep Arch Section

Section number	Weight per lineal foot, pounds	Weight per square foot, pounds	A	B	C	D
DP 165	33 3	25.0	16 in.	5 in.	3/8 in.	5/16 in.
DP 166	42.6	32.0	16 in.	6 in.	1/2 in.	3/8 in.

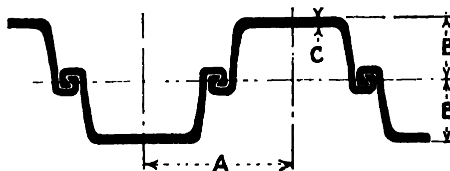
JONES AND LAUGHLIN STEEL SHEET PILING



Extended Channel Section
32.5 lb per lineal foot
23 75 lb per sq. ft of wall

Channel Section
32.5 lb. per lineal foot
27.0 lb per sq. ft. of wall

LARSSEN STEEL SHEET PILING



Larssen Steel Sheet Piling

Section number	Weight per lineal foot, pounds	Weight per square foot, pounds	Section modulus per foot of wall	A	B	C
Ia	22.3	17	7.07	15 3/4 in.	2 9/16 in.	9/32 in.
I	26.25	20	9 3	15 3/4 in.	2 15/16 in.	5/16 in.
II	32.8	25	15 8	15 3/4 in.	3 15/16 in.	13/32 in.
III	42 0	32	25.35	15 3/4 in.	4 7/8 in.	9/16 in.
IV	50.5	38.5	37.89	15 3/4 in.	6 1/8 in.	39/64 in.
V	67.63	49	55.1	16 9/16 in.	6 3/4 in.	7/8 in.

8. Pile Driving and Pulling Equipment.

8a. Pile Drivers.—A pile driver (Fig. 32) is used in driving either timber or concrete piles and consists of two main parts—the bed and the leads. The bed is mounted on rollers and supports the operating machinery. Pile drivers are mostly steam operated, since steam is commonly used in driving. The operating machinery consists of a vertical boiler, an engine, and a two-drum hoist, one drum for the pile line, the other for the hammer line. The

bed is composed of timber sills long enough to allow the boiler, etc., to be set back far enough from the leads to provide proper balance.

The leads are long vertical members rigidly connected to the sills and framed with backstays to form a tower. They carry sheaves at the upper ends for the hammer and pile lines and along the sides are guides for the hammer. Leads in the smaller drivers are composed of wood, suitably cross-braced, with the front open to allow for placing the pile and for the operation of the hammer. In the larger-sized drivers, leads are made of structural steel. In any case, the leads must be of sufficient length and strength to hoist a pile from a position on the ground to the starting position.

In driving precast concrete piles, the pile driver and its equipment are called on to withstand greater stresses than is the case when timber piles are used. Precast piles of 30-ft. lengths average 4 tons, and larger piles from 6 to 8 tons in weight.

Cranes with leads suspended from the boom are often used, especially when driving sheet piling. Whenever possible, however, fixed leads should be used, as it is extremely difficult to keep the hammer in a vertical position with the swinging lead and, at the same time, to allow the full weight of the hammer to rest on the pile.

In driving piles below the reach of the leads, two methods are available. One employs a "follower," which is a stick of timber with some socketing means of holding the tool in proper alignment. The other method, not so much used, utilizes telescopic leads fitted inside the stationary lead and handled by a third drum.

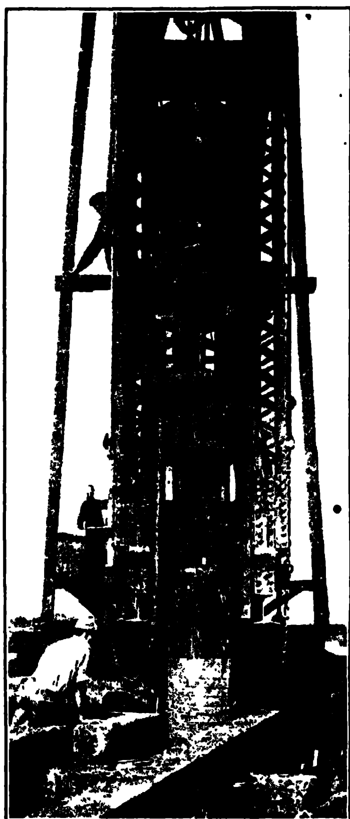


Fig. 32.—Steam hammer showing detail of hinged leads, ram, and driving cushion, Raymond Concrete Pile Co.

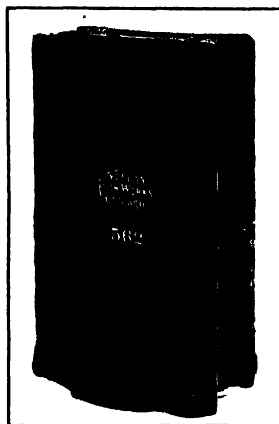


Fig. 33.—Vulcan drop hammer, Vulcan Iron Works Chicago, Ill.

The total weight of a pile driver will depend on the size of pile to be driven and the weight of hammer used. These, in turn, will determine the dimensions and weights of sills, leads, and engine. An approximate weight of a driver using 50-ft. wood leads with a 4000-lb. hammer which will require an $8\frac{1}{4} \times 10$-in. engine weighing 12,000 lb. will be 15 to 18 tons.

Where jetting is to be carried on in conjunction with pile driving, the driver is equipped with a third drum or niggerhead to carry the line supporting the jet pipe or pipes.

8b. Pile Hammers.—Hammers are designated, according to their method of operation, as gravity hammers or power-operated hammers.

Gravity Hammers.—Gravity hammers are of two kinds—drop hammers and single-acting steam hammers.

Drop hammers (Fig. 33) are so called because they consist of a weight hoisted in guides to some distance and allowed to fall. At the top is a ring to attach the line, and at the sides are

grooves to fit the guides of the pile-driver leads. Drop hammers are made relatively long to insure bearing in the guides and to prevent jar when the blow is struck. The bottom is made slightly concave if it is to strike the head of the pile direct, but where caps are used the bottom of the hammer is flat. The center of gravity of drop hammers is located as low as possible.

The hoisting and release of drop hammers is accomplished by two methods. One is by means of a friction clutch on the drum, the hammer being hoisted to a desired height, when the clutch is released. The blow is, therefore, equal to the hammer weight falling through this distance less the friction of the guides and the pull to unwind the line from the drum. The other method is to attach the line to a block incorporating triggers which automatically release the hammer at a desired height. Here the full force of weight and distance, less friction of the guide only, is utilized in driving. With the first arrangement, either light or heavy blows may be obtained, and no time is lost in reconnecting line and hammer after the blow is delivered. In the second case, a blow of a set value is

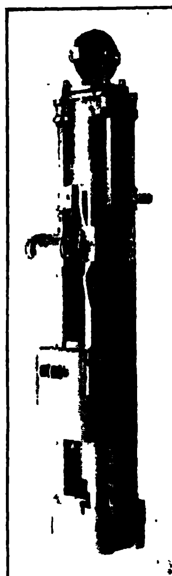


FIG. 34.—Single-acting steam hammer, Vulcan Iron Works.



FIG. 35.—Double-acting steam hammer, Vulcan Iron Works, Chicago, Ill.

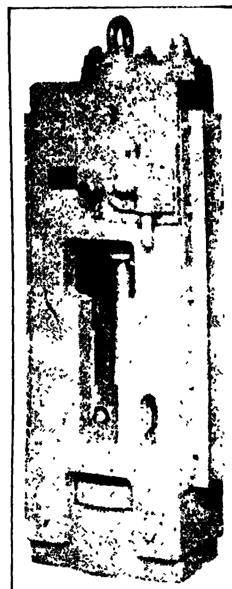


FIG. 36.—Union pile hammer double acting; equipped with standard round pile base.

struck and cannot be altered unless the trip for the trigger is changed. Time is also lost in this method, as the trigger block must fall to connect with the hammer which must again be hoisted before the next blow can be delivered.

The weight of the hammer used with any rig should at least equal the weight of the pile, and best results are obtained when the ratio is about 2:1 in favor of the hammer, so that the pile will be drive into the ground after the inertia of the pile has absorbed its portion of the hammer energy. The fall should, however, not be too great, as time is thus lost between blows. Better results are obtained with a heavy hammer falling a short distance than with a light hammer falling a long distance. An average weight for a hammer is 3000 lb., and falls vary from 5 to 20 ft.

In the steam-operated gravity hammer, usually known as the single-acting steam hammer, the ram is lifted by steam or compressed air and allowed to drop by gravity. The force supplied by the ram is supplemented by the frame of the hammer which is of considerable weight and rests on the pile. The frame is attached to the hammer line and has jaws on the side to engage the guides. The ram mechanism consists of a steam cylinder and a piston. These hammers are useful where a heavy battering action is necessary such as in driving through a layer of shale or of buried logs or loose rock. Most modern hammers use large enough exhaust ports that compressed air can be used interchangeably with steam for power.

Power-operated Hammers.—As in the steam gravity hammer, either steam or compressed air can be used in power-operated hammers. In the latter, however, the ram does not drop by

gravity but is forced down by the expanding gas. Power-operated hammers are usually designated as double acting. The double-acting hammer delivers rapid blows (the largest hammers

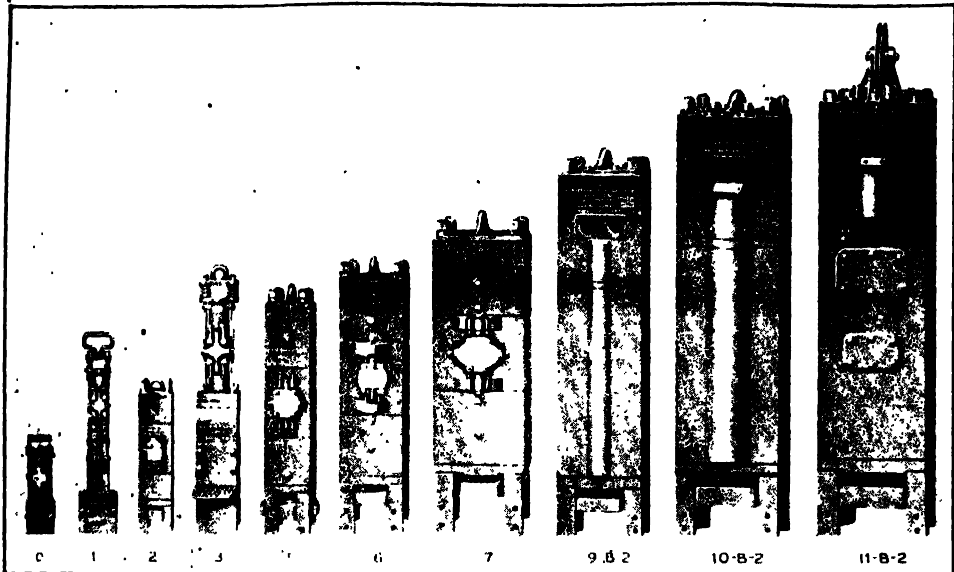


FIG. 37.—McKiernan-Terry pile hammers, double acting.



FIG. 38.—One-man pile hammer driving wood sheeting, Union Iron Works.

two blows per second) of short strokes varying from 3¾ to 20 in. Thus, as compared with the single-acting hammer, which has a stroke of from 36 to 48 in., the double-acting hammer more nearly keeps the pile in motion downward, once it is started; with skin friction largely eliminated, the entire force of the blow can be used to overcome point resistance.

In both single- and double-acting hammers, the weight rests continuously on the pile, and vibration and side sway are effectively reduced. Where the hammer is used without leads, however, some sides way results and makes the hammer's operation far from ideal. In general, the double-acting hammer is lighter, its length of stroke is shorter, its weight of striking parts is less, and the number of blows per minute is greater than in the single-acting hammer. The cost of a double-acting hammer varies from $200 for a 95-lb. hammer suitable for sheet pile work to $3000 for a 13,000-lb. hammer suitable for 21-in. piling.

Numerous advantages are claimed for the single- and double-acting hammers over the drop hammer. Among these are: (1) Serious damage to the piles, such as brooming, splitting, etc., is avoided (especially in using the double-acting hammer), therefore saving the expense of putting rings on the head of the pile and also allowing the use of softer wood; (2) more piles may be driven in a given time with a smaller crew; (3) less injury is caused to adjacent buildings by cracking of plaster, breaking of glass, etc. (the double-acting hammer being more efficient in this regard); (4) the life of the leads is increased three to four times; (5) the cost of driving is less in spite of higher first cost; (6) the speed of driving is greater as the pile is kept in motion (this being more especially true of the double-acting hammer).

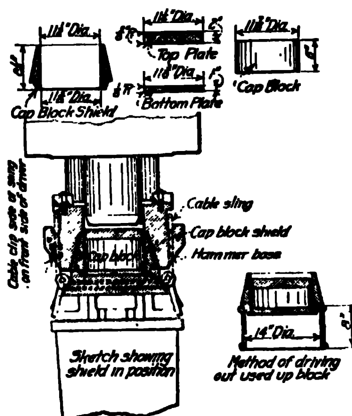
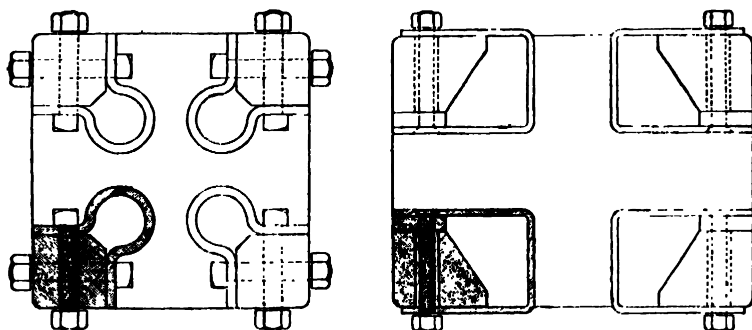


Fig. 39.—Raymond pile cap.

Small hammers suitable for driving wood sheeting can be obtained for one-man operation, striking a 300- to 400-lb. blow and weighing from 100 to 220 lb. They are usually operated by compressed air. Ordinary pneumatic pavement breakers are also fitted with suitable jaws for this work.

8c. Pile Caps and Points.

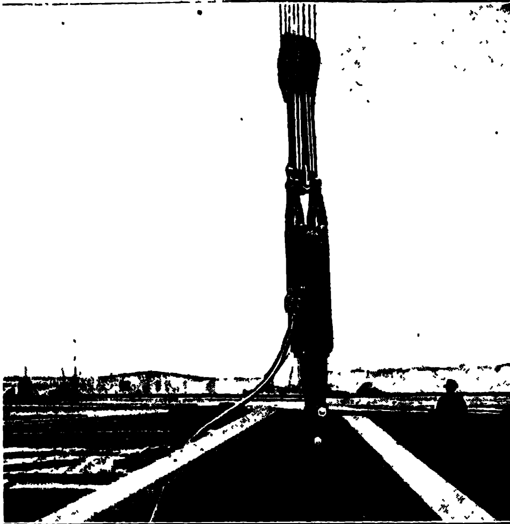
Pile Caps.—When driving timber or concrete piles with gravity hammers, a driving cap is sometimes used between the hammer and the pile head. This cap, in one design, consists of a metal block, one side of which is concave, the other recessed, in which is fitted a round wood cushion block. In cross-section it resembles a drop hammer, having jaws in the side to engage the guides, and is attached to the hammer by rope slings. When a cap is used, the hammer base is flat. If the use of such a cap is insufficient to prevent brooming or splitting of the head of a pile, an iron ring, made from flat wrought iron from 2 × 5/8 to 4 × 1 in. may be forced over it. Such rings may be removed and used over again many times.


Fig. 40.—Filling pieces for McKiernan-Terry hammers.

With double-acting hammers, in driving either bearing piles or sheet piling, caps are not ordinarily used, but, instead, various attachments are available which fit these hammers for the different types of service. Thus, there are special hammer bases for driving round piles, concrete piles, steel sheeting, and wood sheeting. In the last two cases, they are known as filling pieces (Fig. 40).

Pile Points or Shoes.—Timber piles drive better in ordinary ground and with less danger of spreading if the tip is square and without point or shoe. This also gives a better footing to the pile. When coarse gravel, boulders, and the like are encountered, the pile is preferably pointed to reduce sticking and crushing. Likewise, in hard compact earth which must be displaced,

pointing is found to give better results. Metal shoes are provided in some cases when boulders, riprap, very hard clay, and hard sand are encountered. Several types are in use, but the type which gives a square bearing to the tip of the pile and also sufficient socket to make the



1.—Pulling steel sheet piling with inverted hammer. McKiernan-Terry Drill Co., N. Y.

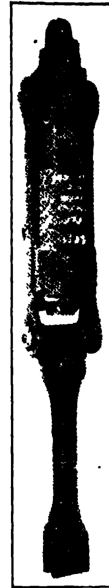


Fig. 42.—Air or steam sheetpiling extractor, Vulcan Iron Works.

pile and the shoe act together is the most desirable. Some shoes for wood piles are made with a rod which fits into the center of the pile as an additional means of holding the pile and shoe together. This rod is from 8 to 12 in. long and requires that provision be made for it in the pile. Precast concrete piles, if of good quality, should not require driving shoes.



Fig. 43.—Lackawanna pile puller, Bethlehem Steel Company.

Caps and shoes are not generally required for timber sheet piling, as, due to its section such protection is not necessary. In some cases, a bolt or short point is attached but as a means of keeping the groove clean throughout its length so that grouting may be employed to insure a tight waterproof joint rather than as a penetrating point.

Steel sheet piling requires no shoe, as it will cut its way through almost any material but hard rock, and the top is sufficiently resistant to withstand the hammer blows without serious injury.

8d. Pulling.—Sheet piling is usually removed when that part of the work for which it has been necessary has been completed. Piling may be removed by jacks, by inverting a double-acting hammer, by levers, or by special pullers. Sometimes, round piles must be pulled, in which case a sling is put around the head and attached to a long lever, this lever being operated by derricks, jacks, or some other convenient means with new hitches taken as the pile moves upward. Often it is necessary to strike a few blows with a hammer to start a pile or else to keep the sling taut for some time before the pile begins to move.

In pulling steel sheet piling, best results are obtained by using a special puller or by inverting a double-acting hammer whose rapid, short strokes tend to jar the pile loose. Once the pile is loose, pulling is easy. In using an inverted hammer, a yoke of steel plates having holes drilled in it to correspond with holes in the piling is fastened to the latter by bolts (Fig. 41). A better method than using the rigid steel yoke is to substitute a wire cable. This will flex as the hammer pulls sideways, while the rigid yoke will either break or become permanently distorted. Several special pullers are shown in the accompanying illustrations.

PUMPING EQUIPMENT

By Waldo G. Bowman

Water in excavations or in footings or trenches must be removed by pumping. For building excavation work, there are available diaphragm pumps, siphons, steam pumps, centrifugal pumps, and reciprocating pumps. The size and type of pump to be provided on a particular job will depend upon the relative positions of the suction and discharge, upon the amount of water, and upon the amount of sediment carried by the water.

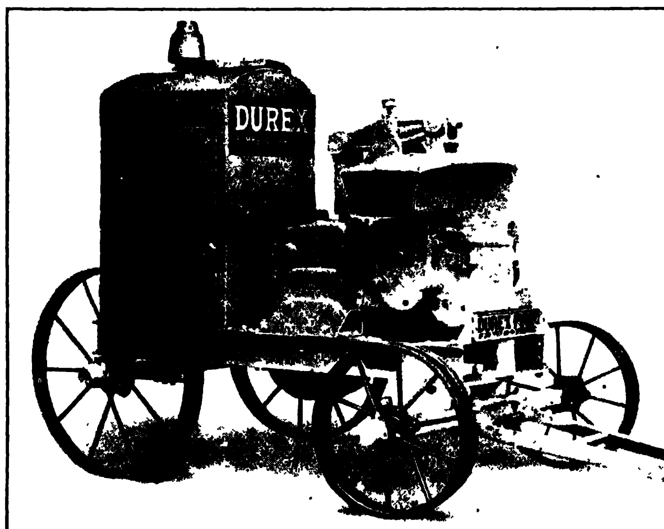


Fig. 41.—Open-top diaphragm pump, Chain Belt Company, Milwaukee

9. Diaphragm Pumps.—The diaphragm pump is one of the most used types of pump, if not the most used type, for building foundation work. It consists of a rubber diaphragm containing a flap valve, mounted horizontally in a cylindrical frame. Connected with the center of the diaphragm is a pivoted arm which when moved causes the diaphragm to act as a piston of large area and short stroke. The suction line connects with the space beneath the diaphragm, and the discharge is above the diaphragm. In the open-top diaphragm pump, the water merely flows from the top of the diaphragm, while in closed-top diaphragm pumps it is forced out through a discharge pipe. Diaphragm pumps are actuated either by gasoline engines or by electric motors.

Diaphragm pumps are noted for their ability to handle water containing mud, sand, gravel, etc. They will also work satisfactorily even though the water supply varies or disappears entirely, in the latter case running dry without damage, usually "picking up" the suction whenever sufficient water accumulates around the suction-pipe opening. Open-top diaphragm pumps naturally must be placed above the drain into which the pump discharges. The closed diaphragm pump may be used in this same way, but it is primarily intended to be used wherever the discharge point is located above the pump. In deep excavations, closed-top diaphragm pumps can be placed 20 or 25 ft. above the water level, and the discharge hose led up over the edge of an excavation to a height dependent on the pressure available. Diaphragm pumps are available in single or double types. They are usually furnished

mounted on steel trucks, although skid mountings and two-wheel or four-wheel rubber-tired mountings can be had. The capacity range in diaphragm pumps is between 40 g.p.m. for a single-pump unit to 325 g.p.m. for a double-pump unit. Conservative rating for water lift is 20 ft. for the open-top and 30 ft. for the closed-top diaphragm outfit. The usual suction-pipe size on diaphragm pumps is 3 or 4 in.

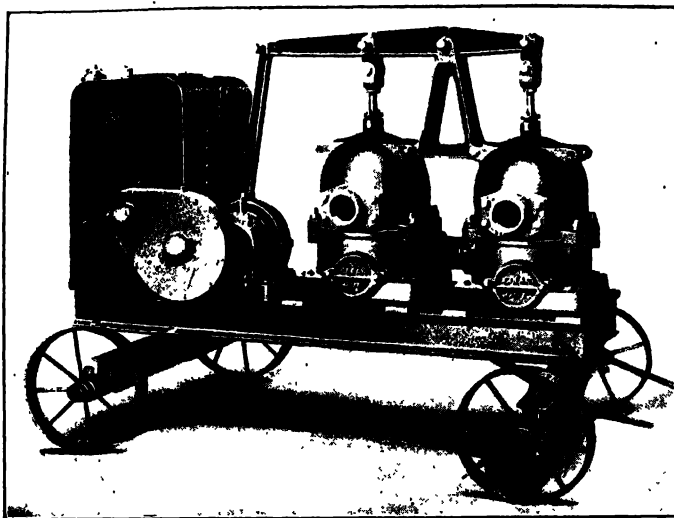


Fig. 45.—**Double closed-top 4-in. diaphragm pump, Novo Engine Co., Lansing, Mich.**

10. Steam (Syphon-type) Pumps.—An economical steam-actuated pump, much used in construction work, operates on the familiar ejector plan. Its lift is limited, but the amount of water handled ranges from 5 to 200 g. p. m., according to size and to boiler pressure available for its operation. Its main advantages are portability and freedom from breakdowns, since there are no moving parts. The *pulsometer* (Fig. 46) is one design of this type of pump. It is said to operate satisfactorily even when stones as large as 6 in. in diameter are to be removed with collected water. Having no moving pistons the pump will not clog; and by having large valves, stones and refuse of considerable size will pass. In most installations, the pulsometer is suspended by a chain or rope over the water to be removed as shown in Fig. 46. Steam and water connections are made with rubber hose so that the outfit is easily moved from place to place. Pulsometers may be connected in series where the total lift is greater than the lifting ability of one alone.



Fig. 46.—Pulsometer steam pump in operation. Pulsometer Steam Pump Co., N. Y.

11. Centrifugal Pumps.—Centrifugal pumps comprise a circular or spiral casing having suction at the center with discharge at the outer circumference. They are made vertical or horizontal (meaning the position of the axis of rotation), but the latter is more common since the means of driving is simpler. Ordinarily, these pumps are directly connected to gasoline engines or electric motors. Inside the casing is a circular disc or impeller provided with curved vanes which revolves at high speed, throwing the water outward so that it escapes through the discharger under pressure. Pumps of this type are made either single or multiple stage, the latter being several units placed in one casing to increase the lift. No valves, except a foot valve on the suction line, are required, and for this reason a certain amount of sand can be handled with the water.

Centrifugal pumps are particularly suited to handle large quantities of water when the supply of water is constant, so that the suction pipe is kept covered. In the event of air getting into the suction, some means of priming must be resorted to such as a pet cock in the top of the casing through which the pump and casing can be filled with water. Suction diameters vary in size from 3 to 10 in., with corresponding variations in the capacities in gallons per minute of from 100 to 2500.

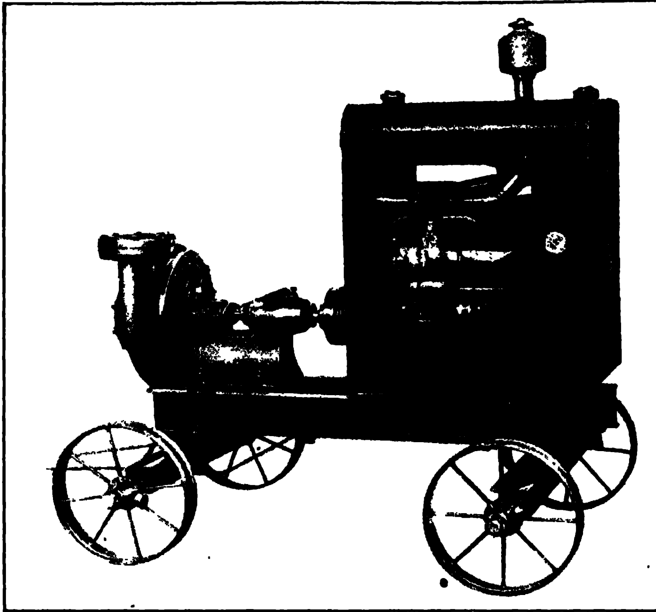


Fig. 47.—Centrifugal pump direct connected to gasoline engine, Novo Engine Co

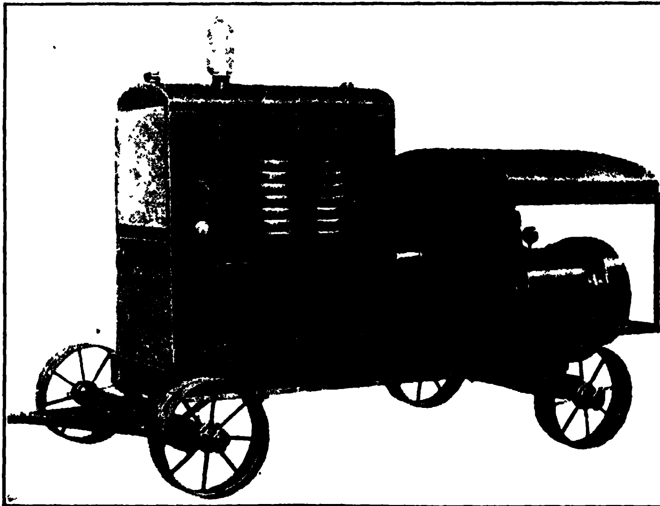


Fig. 48.—Triplex outfit pumping 110 g.p.m. at 450-lb. pressure, Novo Engine Co.

12. Reciprocating Pumps.—Reciprocating pumps consist of one or more cylinders with inlet and discharge valves, opened and closed when the piston is moved back and forth in the cylinder (usually by means of gearing and a crank and pitman). On the other hand, steam

power is sometimes used, in which case the pump has cylinders on both ends of the piston rods, one end for steam, the other for the water. Single-acting pumps are those in which the fluid is admitted at one end of the cylinder only and is delivered when the piston or plunger is travelling in one direction. In a double-acting pump, the fluid is admitted at both ends of the cylinder and is delivered at both strokes of the piston. Reciprocating pumps with two or three cylinders are known as duplex and triplex pumps respectively. The advantage of the multi-cylinder type is that the discharge flow is more uniform than can be obtained with a single-cylinder pump.

Reciprocating pumps utilizing a special patented oiling system have been developed by the Novo Engine Company for unusually high-speed pump operation. Whereas, 65 to 75 r.p.m. of the pump crankshaft is ordinarily a maximum on heavy-duty plunger pumps, the triplex pump of the above design operates at 200 r.p.m. The result is unusually smooth pump operation. The single-cylinder double-acting piston pump of this design is available with a 2-in. suction and discharge opening and in various capacities from 25 to 55 g.p.m. The duplex double-acting pump is available in 2-, 2½-, and 3-in. suction and discharge, with displacements varying from 5 to 100 g.p.m. The triplex, single-acting pump is available in a 3-in. suction and discharge size and has a displacement of 80 to 100 g.p.m. with a pressure range of from 400 to 500 lb. per sq. in.

CONCRETE EQUIPMENT

By Waldo G. Bowman

Concreting, including both the manufacture and the placement, is probably more dependent upon equipment than any other means of construction. As the demands placed upon concrete structures increase, this equipment becomes more varied and more complex. Handling forms, bending and handling reinforcement, storing and handling aggregates, proportioning, mixing, and placing concrete, each requires special machines. The first responsibility of the concrete-building contractor should be to see that he has the best and most modern equipment available.

13. Forms.—Wood forms can be constructed on the job. Ordinary carpenter's tools can be used, but if the amount of work is large, electric or air motor handsaws or gasoline or electric-powered saw tables are available. Steel forms for columns and for ribbed and flat-slab floors are available from several manufacturers. Ordinarily, these forms are rented and not sold. Or the company furnishing the forms will do all formwork with its own forces under a subcontract. Dependent upon the size of the floor panels, their weight, and the headroom available, one or another method of handling forms may be adopted. Derricks, gin poles and winches, or blocks and falls enable even large sections to be readily handled. Smaller sections may be better handled manually. Initial loosening of forms may be brought about by pinch bars or other levers, by pulling with blocks and falls, or by jacks, care being taken not to pry against green concrete.

14. Bending Reinforcement.—Fig. 49 shows the Universal bar bender which may be fastened to any bench or plank. It is a light portable device weighing about 60 lb. and capable of bending all ordinary sizes of reinforcing bars to any angle desired without any adjustments, being necessary. The top half of the bender can be removed and used to bend bars after they are in place. The bar rolls around the pin in bending, thus distributing the strains along the bar and reducing the chances of fracture at the bend. The bender is equipped with a 5-ft.-long crowbar for a handle which may be removed and used for other purposes. To bend large reinforcing bars easily, the handle should be lengthened by using an iron pipe over the crowbar. A similar bender, manufactured by the Ransome Concrete Machinery Company, and shown in Fig. 51, will bend bars up to 1⅛ in. square or round. With this machine the size of bend may be varied by moving the pin. Once the pin is set, the handle is pulled the full distance, and all resulting bends are exactly equal.

A bar bender designed for heavy work is manufactured by the Wallace Supplies Company, Chicago, Ill. This machine has an auxiliary ratchet lever which operates a pinion against a series of teeth in the frame at a large ratio, thus developing great power. The ratchet panel may be thrown out of engagement, and the machine operated with the regular lever for light work.

Fig. 52 shows a power-operated bar bender designed to bend any size of reinforcing rod that is likely to be used in building operations. Any size of bar from ¼ to 1¼ in. round, square, or deformed can be bent to any angle desired; or spirals formed from 6-in. diameters to any required size. The weight complete, ready for shipment, is 2700 lb. The machine is manufactured by Kardong Bros., Minneapolis, Minn.

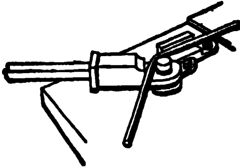


Fig. 49.—Universal bar bender.

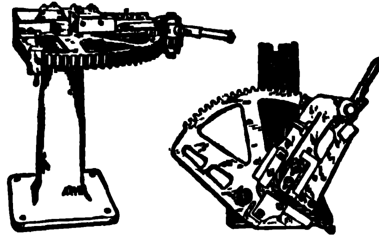


Fig. 50.—Wallace bar bender.

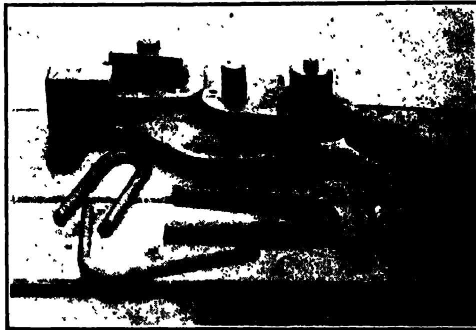


Fig. 51.—Ransome bar bender.

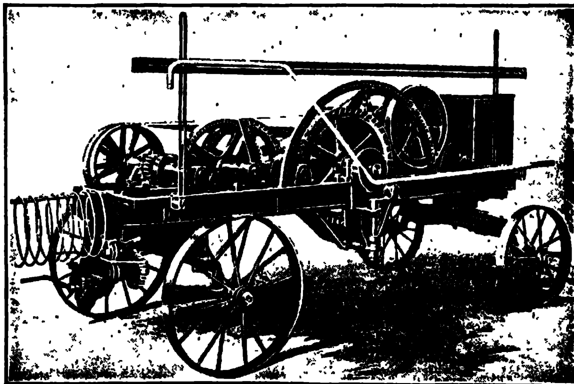


Fig. 52.—Power-operated bar bender.

15. Storage and Handling Aggregate.—Sand and stone for the aggregate may be stored either on the ground or in overhead bins. The most usual equipment consists of steel bins, one each for the sand and stone, mounted over the mixer and discharging into it by gravity. These bins are originally charged by a crane operating a clamshell bucket, by a bucket loader, or by material elevators as shown in Fig. 64. These elevators are available either open or enclosed and in capacities ranging from 30 to 60 cu. yd. per hour.

Steel or wooden bins are available from various manufacturers. The requisities of a storage bin are (1) steep slope of sides; (2) absence of bolts, nuts, or rivet heads within the bin;

(3) no flat bottom area; and (4) easy erection and dismantling. Bins are available either in one-compartment or two-compartment types, the one-compartment type holding from 15 to 40 tons, while the two-compartment bins range from 20 to 300 tons. Special three- and four-compartment bins are also available. In building operations it is often possible to locate the mixing plant in the basement with the bins above and their tops at either the first- or the second-floor level. The bins can thus be charged from motor trucks running into the building on a ramp. It will be necessary to compare the space available with the desired capacity of the mixing plant in order to determine the size of bin required.

16. Proportioning.—Proper proportioning of the ingredients of concrete is as important as the mixing operation. Three methods of proportioning are in use—by volume, by weight, and by inundation, the last being a volume measurement for sand in a completely submerged state. Special batching equipment is necessary and available for all three methods.

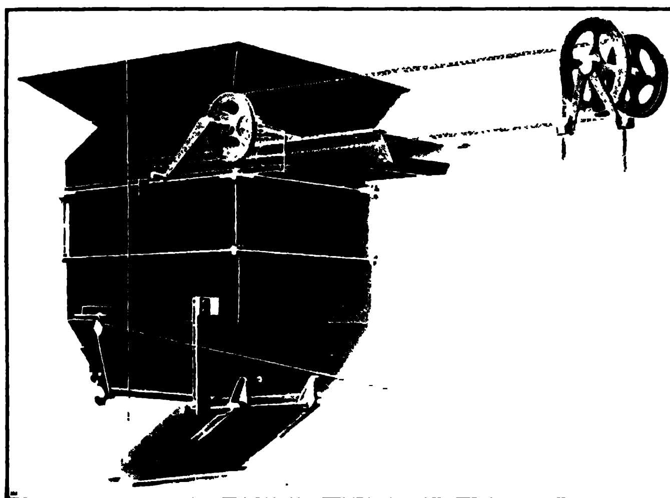


Fig. 53.—Blaw-Knox adjustable volumetric batcher.

Where aggregate storage is on the ground and bucket elevators are used, batchers are sometimes attached to the top of the bucket elevators. Where bins are used, the batchers are attached directly below the bins and over the mixer.

Volume batchers (Fig. 53) are steel hoppers equipped with a hinged door on the bottom, a means for quickly and accurately changing the volume, and a strike-off gate which levels the material at the same time that it closes the bin discharge. Such batchers are furnished by the Blaw-Knox Company in two sizes: (1) minimum 9 cu. ft. to maximum 36 cu. ft. and (2) minimum 1½ cu. ft. to maximum 13 cu. ft.

Batching by weight provides greater accuracy. Particularly is this true in measuring fine aggregate and sand where the bulking, due to moisture content, causes inaccuracies in volume measurement. Commercial sand bulks from 15 to 30 % in volume, and the possible inaccuracies in measurements by volume are thus seen to be considerable. In measuring by weight, the chief error arises in the inclusion of the weight of the moisture in the sand, but this can be easily determined and compensated for. The weighing batcher (Fig. 54) is similar in appearance to the volume batcher. It is a steel hopper connected by a system of levers to a standard beam scale. Weighing batchers are available in single or double types, the single type weighing the fine aggregate only, while the double type weighs both the fine and the coarse aggregate. For measuring bulk cement, specially tight weighing batchers are available and useful. Adjustable baffles are included in the weighing hopper so that an approximate setting of the hopper capacity can be made by volume for the weight of the batch of material to be measured. An auxiliary dial scale which attaches to the beam scale is furnished to register the last 200 lb. of material to be weighed. The baffles and the auxiliary dial are means of speeding up the operation of weighing batchers. Blaw-Knox weighing batchers are furnished in 1-, 2-, 3-, and 4-ton sizes.

Inundation is a method of measuring sand which eliminates the inaccuracies due to moisture content. At the same time it makes possible the determination of the exact amount of water, including the original moisture content of the sand, which is used in the mix. The inundator is founded on the principle that the volume of all sand is constant when the sand is completely saturated or inundated. It consists (Fig. 55) of a self-dumping and righting

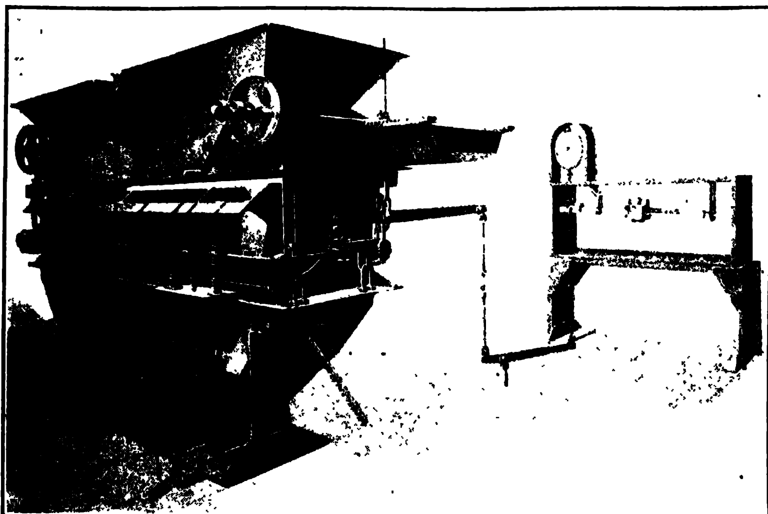


FIG. 54.—Blaw-Knox weighing batcher.

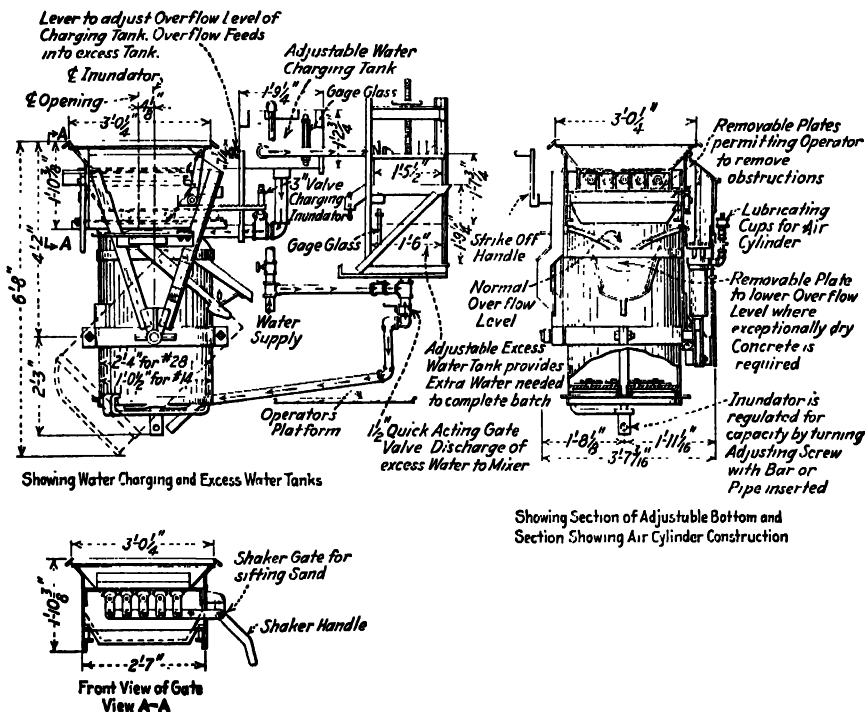


FIG. 55.—Blaw-Knox inundator.

steel container with an adjustable bottom, a shaker gate, a strike-off gate, an excess-water measuring tank, and a water-charging tank. The inundator is suspended beneath the bin in the same manner as are other batching systems. The excess-water tank measures the additional water required for the batch over that which is necessary to inundate the sand completely. The inundators above described are adapted to medium and large installations. There is also manufactured a small inundator for use on the small job. It is operated manually, being mounted in a two-wheel frame similar to that used on a concrete buggy. These small inundators are available in capacities from 1.9 to 3.44 cu. ft.

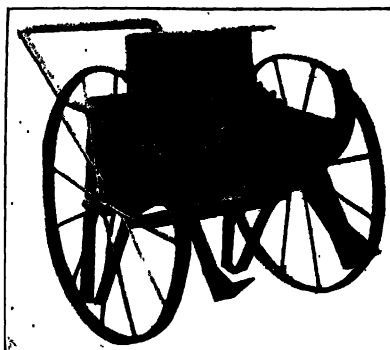


Fig. 56.—Blaw-Knox junior inundator.

17. Types of Mixers.—All mixing of concrete for building operations should be by machine. Two types of mixers suitable for building operations may be classified as the drum mixer and the trough mixer. Gravity mixers, consisting of a series of large funnels suspended one above another and permitting material to flow from one into the other by gravity, have been used but are seldom seen any more. Their efficiency is far inferior to that of the other types. In addition to the gravity mixer, pneumatic mixers are available, but they seldom are adaptable to

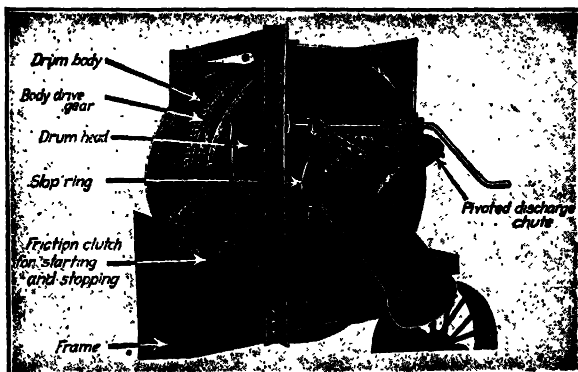


Fig. 57.—Drum mixer.

building operations. Their use has been confined to tunnels and similar construction, where access to the forms is particularly difficult. Trough mixers are of the paddle or shovelling type and are useful only for mortar and plaster mixing. The drum mixer, which includes the barrel shape as well as the drum shape itself, is exclusively used for concrete mixing at the present time.

17a. Drum Mixers.—The mixing action in drum mixers is accomplished by agitation, lifting, and pouring of the several materials by blades and scoops attached to the inside of the mixer drum. With the exception of the tilting or barrel mixers, discharge of the

materials from the drum is accomplished by inserting a trough into one side of the drum in such position as to catch the concrete as it is poured from the mixing blades. Barrel mixers discharge by tilting the drums.

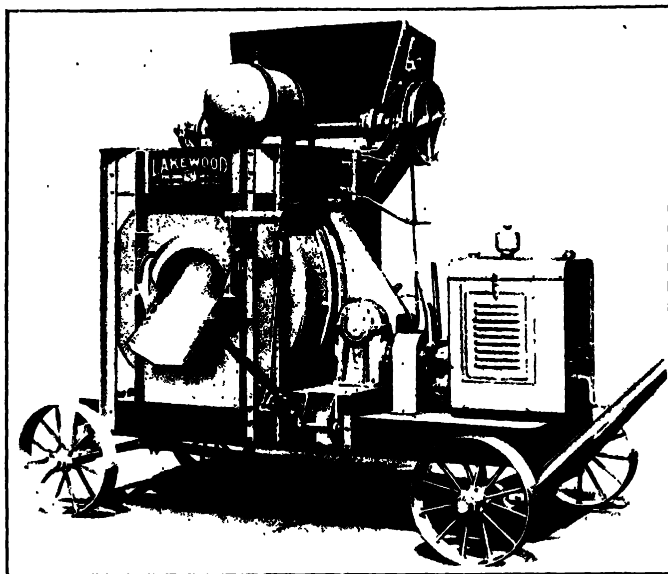


Fig. 58.—Lakewood 14-S mixer.

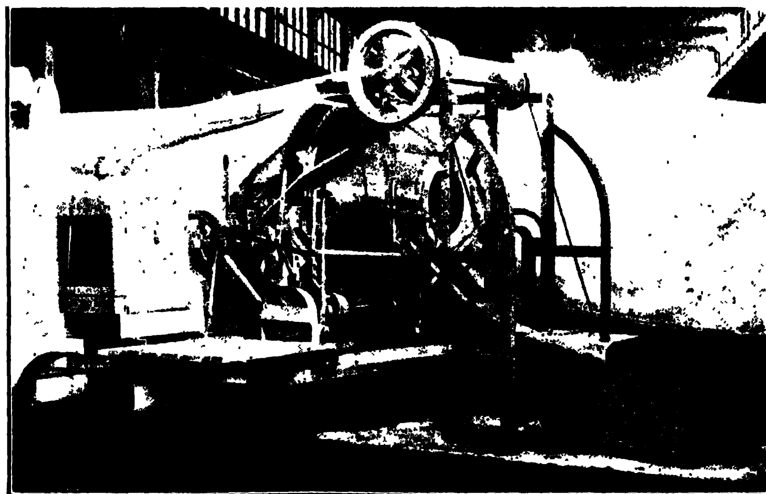


Fig. 59.—Smith 21-S barrel or tilting mixer.

Building mixers are available in certain standard sizes agreed upon by the Mixer Manufacturers Bureau, an association of most of the concrete-mixer manufacturers in the country. According to the latest mixer standard, seven sizes of construction mixers are standard, as follows: 3½-S, 5-S, 7-S, 10-S, 14-S, 21-S, and 28-S. No intermediate sizes are manufactured, although sizes below 3½-S and above 28-S may be. The figure in the

size approximately equals the guaranteed capacity in cubic feet of mixed concrete per batch. The letter S designates construction mixers as against the letter E which is used for paving mixers. Construction mixers are guaranteed to hold their rated capacity when operating on level grade. Water-measuring tanks for each size of construction mixer have sufficient capacity to deliver the following minimum quantities of water per batch: 3½-S, 6 gal.; 5-S, 8 gal.; 7-S, 12 gal ; 10-S, 18 gal.; 14-S, 24 gal.; 21-S, 36 gal.; 28-S, 48 gal. Standard sizes of construction mixers are guaranteed to hold and properly mix the batches shown in the accompanying table.

Proportion and Size of Batch in Bags of Cement for Various Standard-sized Mixers

Proportions	3½-S	5-S	7-S	10-S	14-S	21-S	28-S
1:1½:3	1	1	2	3	4	6	8
1:1½:3½	½	1	1	2	3	5	7
1:2:3	½	1	1	2	3	5	7
1:1¾:3½	½	1	1	2	3	5	7
1:2:3½	½	1	1	2	3	5	7
1:2:4	½	1	1	2	3	4	6
1:2½:4	½	1	1	2	3	4	6
1:2:5	½	½	1	2	2	4	6
1:2½:5	½	½	1	1	2	4	5
1:3:5	½	½	1	1	2	3	5
1:3:6	½	½	1	1	2	3	4



Fig. 60. – Rex 3½-S tilter on rubber-tired trailer, Chain Belt Co., Milwaukee, Wis.

17b. Time of Mixer Operations.—In charging and discharging the mixer, a time limit is imposed both by the physical laws governing the flow of material from one container to another and also by the physical limitations of operatives and of the mechanism itself. Inasmuch as the time during which the materials remain in the mixer is fixed by specification, speed in mixer operation must be gained in charging and discharging. Many power-loading mixers at the present time synchronize the charging and discharging operations in such a manner that they overlap one another. Should the mixer be charged by wheelbarrows, the time, of course, is governed by the efficiency of the layout and the men. Sufficient time should be given to the mixing operation itself. Seldom is too long a period of mixing used, so care should be to increase the time of mixing. Common lengths of time for mixing are 1, 1½, and 2 min. These assume a clean and efficient mixer. Mixers with the drum half choked with concrete or the blading so worn that it cannot handle the materials will, of course, not operate efficiently.

The manner of loading the mixer will be determined by the plant layout. In case overhead bins are used, charging may be by gravity. In case storage of material is in the street or on the floor, mixers using power loaders are best. These have the advantage of low loading as well as relatively high discharge of mixed material. All paving mixers are of the power-loading type,



Fig. 61.—A modern concreting plant.

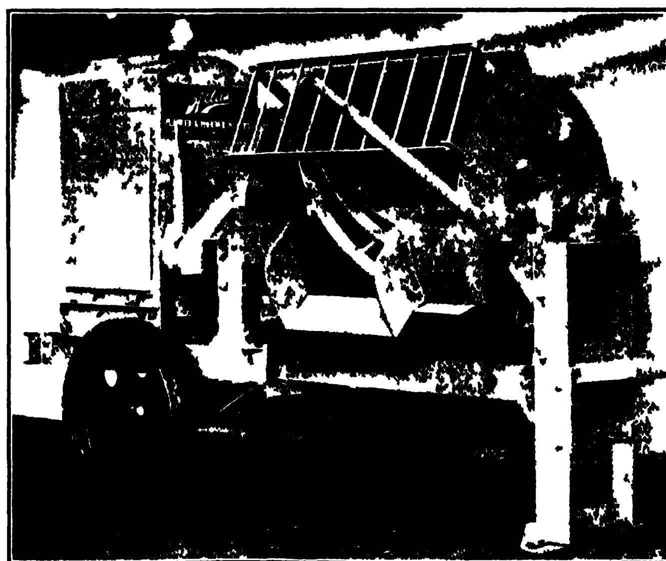


Fig. 62.—Shoveling type mixer for mortar or plaster. Chain Belt Company.

and many building mixers follow the same general design In case a power-loading mixer is not available, ramps may be built up to the charging opening to permit wheelbarrow operation

18. Ready-mixed Concrete In many cities, particularly the larger ones, central mixing

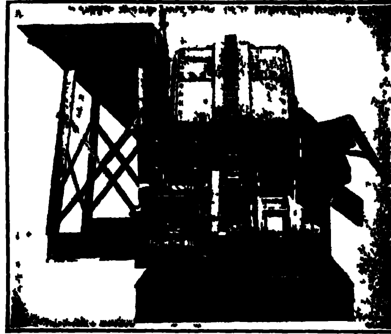


Fig 63 —Charging hopper mounted on mixer frame

plants have been installed from which ready-mixed concrete can be purchased in quantities for large or small jobs In some cases, the concrete leaves the plant in its wet and final form, while in others it is placed in the truck dry and water is added just before arrival at the forms Both

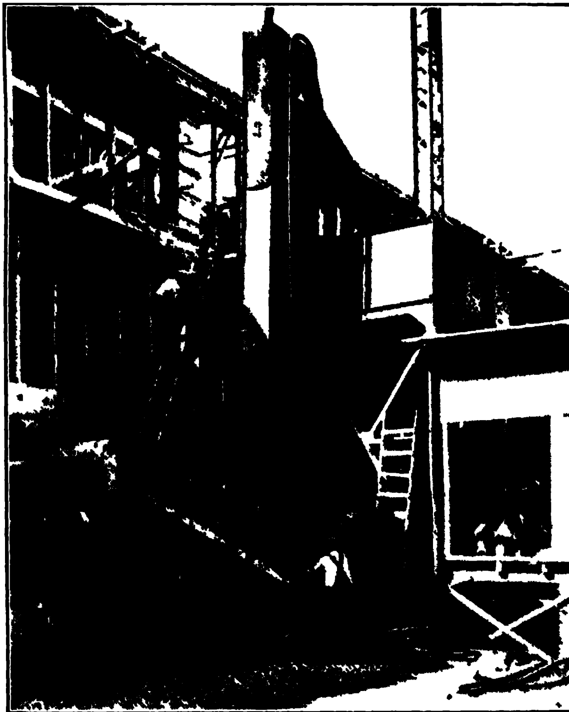


Fig 64 —Enclosed bucket elevator charging bins.

methods require special truck bodies. One type of body for hauling wet concrete is shown in Fig 65. Another type is in the shape of a cylinder which is revolved by a gasoline engine during

transit to insure against segregation. The mixer shown in Fig. 66 takes the batch dry and adds water in transit. Two water tanks are provided. One contains the exact amount of water for the batch, while the water in the other is used for flushing the mixer after the batch is dumped. The barrel is rotated by the truck engine through a power take-off. Blades and baffles in the drum provide the mixing action.

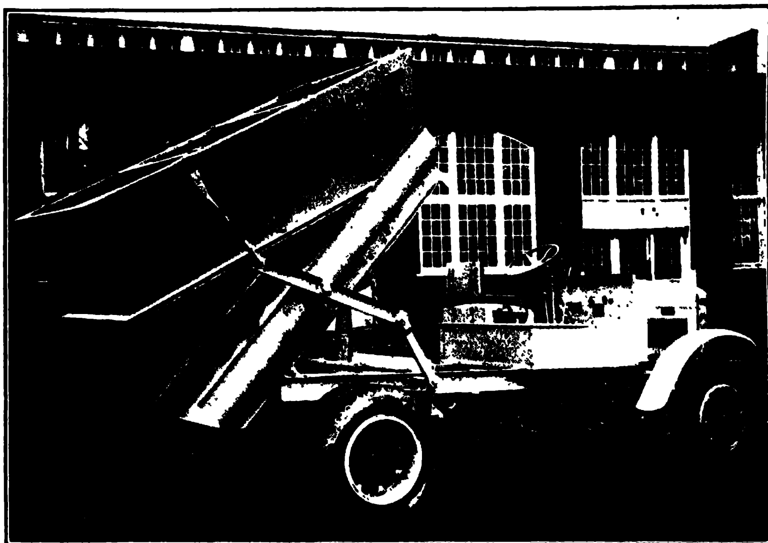


Fig. 65.—Special truck body which remixes wet concrete as it is dumped, Hug Co., Highland, Ill.

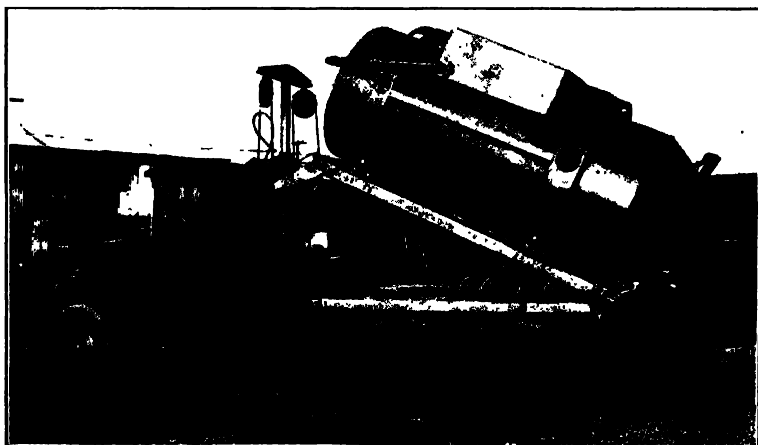


Fig. 66.—Equipment for mixing concrete in transit, Transit Mixer Co., Inc., San Francisco.

19. Transporting and Placing Concrete.—Providing means for transporting mixed concrete and for placing it properly in forms, both in first cost and in ultimate effect, ranks equal in importance with the operations of proportioning and of mixing raw materials. The means usually adopted include some sort of bucket, open spouts or chutes, barrows or carts, or belt conveyors.

19a. Barrows. The use of barrows involves less original plant outlay than any other method. On the other hand, the ordinary wheelbarrow having a flat pan is not well adapted to distribution of concrete. With such a barrow a man can handle about 1½ cu. ft. of mixed concrete. The man's working rate is necessarily cut down by the care which is required to keep the material from slopping over the side. Furthermore, by the design of the barrow a large proportion of the weight of the load is on the man's arms rather than on the wheel. Deep-pan barrows have been designed to overcome this difficulty but have not wholly accomplished the desired end. Two-wheel concrete carts (Fig. 67) are better adapted to this work than wheelbarrows, both because they can carry a larger load and because this load is balanced on the wheels themselves with little or no strain on the operator. The usual two-wheel concrete cart is of 6 cu. ft. capacity in which 4½ cu. ft. of mixed concrete can be carried by one man.

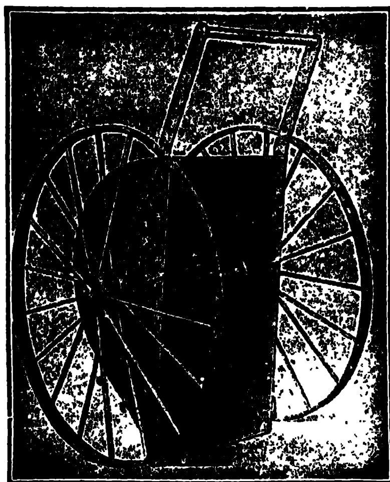


Fig. 67.—Concrete buggy.

19b. Buckets.—There is a great variety in types of buckets adapted to the distribution of concrete. Some of these buckets are straight-side skips adapted to dump by overturning. Others are bottom-dumping buckets operated by a man at the form. These bottom-dumping buckets may be of various patterns adapted to some particular use. An example of this sort of bucket is shown in Fig. 14 in which the bottom is so constructed as to form a long narrow opening, actuated through a powerful lever mechanism.

19c. Spouts or Chutes.—Handling concrete through spouts or chutes is more usual than any of the foregoing methods with the possible exception of distribution in carts. To raise concrete vertically in a tower located at the central mixer plant and distribute it by gravity through the chutes which can be arranged in convenient sections to cover any area within a radius of 300 ft. from the base of the tower appeals strongly both to engineering and to business sense. Yet, in spite of its many good points the convenience of spouting has brought about many abuses.

In all spouting installations, care must be taken to have the chutes at a working inclination. Furthermore, it is important to maintain a uniform pitch throughout the entire line in order that the flow may be even and uninterrupted. The pitch, also, must be greater when the material is to be carried to a considerable distance than when it is to be carried only a short distance, since in the former case the friction of the concrete in the chute tends to overcome its initial momentum. A slope of 1 vertical to 3 horizontal is almost universal practice. It will be found that a somewhat steeper slope at times may be necessary, especially when using aggregate coarser than 2 in. Concrete with a slump as low as 2½ in. can be handled in chutes if they are properly arranged. An important thing to

remember in connection with chuting is that uniform mixing of the conc wh in every batch is alike, eliminates many of the troubles sometimes encountered with chuting plants.

The size of chute used should have a cross-section ample to convey, when it is running not more than two-thirds full, all of the concrete that it may be called upon to handle. Ordinary-sized chutes have a width of 12 in. and a depth of about 10 in. for the smaller sizes, and in the larger sizes a width of 18 in. and a depth of about 15 in. Flexible chutes for vertical distribution are ordinarily 10 in. in diameter.

19d. Sections Used in Chuting.--It is desirable that concrete chutes be arranged in a series of units which may be assembled in various combinations. Continuous-line chuting should be changeable to swivel-head or vice versa, as the conditions of the work require. In Fig. 69 are shown a number of chute sections. All of the chutes shown, with the exception of the one at the bottom, which is a continuous-line chute, are types of swivel-head chutes. The swivel-head chute has a hopper at the upper end and a deflecting plate at the lower end. In assembly, the swivel head of one chute is suspended by a hook and cross-bolt from the swivel plate of the chute preceding it. Such chutes are made in lengths varying from 10 to 50 ft., and longers units are trussed. In a continuous-line chute, provision is made for attaching chains for support from an overhead cable.

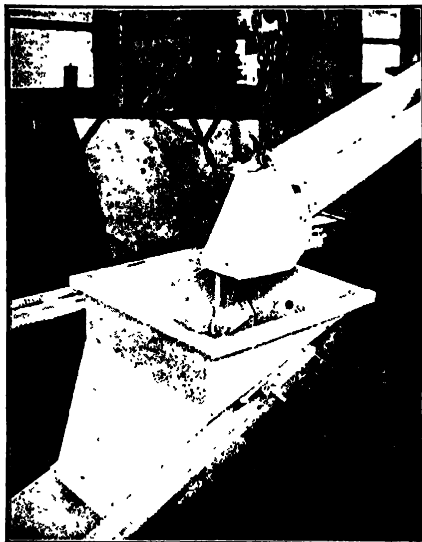


Fig. 68.—Swivel hook.

It is desirable to keep the number of chute supports to a minimum, and for this purpose counterweight chutes have been developed. Such a chute is provided with trussing, on the rear end of which a counterweight is placed. Counterweight chutes vary in length from 30 to 50 ft. and are easily shifted. In addition to the several types of chutes, numerous accessories are available such as various types of hoppers, line gates for diverting the concrete to a line of vertical chuting, and hopper switches for diverting concrete to either of two lines of chuting or dividing it between them.

Fig. 68 shows the swivel hook used in making the flexible joint between successive trough sections; the upper line of spouting is supported by a fall and tackle attached to the bail on the splash hood, while the lower line is supported by the swivel hook, connecting the lower hopper head with the splash hood of the upper line. The swivel hook is kept clear of the path of the concrete.

The greatest items of expense in chuting plants are first cost, installation, and maintenance. Maintenance charges are particularly heavy. The ordinary stock chute which is made of No. 12 or No. 14 gage metal can seldom handle more than 2000 to 3000 cu. yd. without renewal due to the abrasive action of the material. Because of this fact some chutes are originally sold with renewable liners.

FIG. 69.—Various types of chuting sections, Ransome Concrete Machinery Co., Dunellen, N. J.



FIG. 70.—Flexible spouting.

19e. Towers.—Towers may be of either wood or steel. Also, the tower may be of typical four-post type, or it may be a single mast if made of steel. Such masts are coming into use as a most efficient unit on all types of building construction. Most of the steel-tower and steel-mast plants available have provision for quick and rapid shifting of the tower hopper upward or downward, thus giving positive and flexible adjustment to the chuting plant. Either towers or masts can be erected to practically any height. They are assembled in 15- or 20-ft. sections.

The concrete bucket, lifted by a hoist at the mixer, operates within the tower, while in the case of a mast plant it slides on one face. On the opposite face of the mast a material elevator can be operated if desired. The buckets used are generally of the tip-over type, dumping automatically at the tower or mast hopper by the engagement of a roller on the front corner

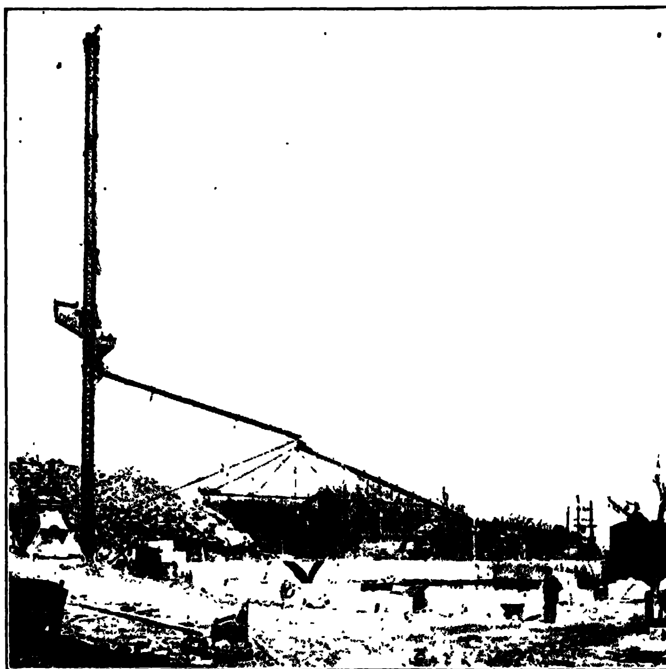


Fig. 71.—Mast hoist with boom and counterweight chute, Insley Mfg. Co., Indianapolis, Ind.

of the bucket with a switch connected to the hopper. The size of the mixer is the governing factor in determining the size of the bucket, since buckets are furnished in sizes to suit any standard mixer.

19f. Chuting Plants.—Chuting plants may be classed as boom-chute plants, boom-and-counterweight-chute plants, and continuous-line plants.

Boom-chute Plants.—In this type, a 30- or 40-ft. section of chute is seated at its upper end on a bracket just below the hopper, and the lower end is tied back to a bridle just above the hopper. An additional swivel-head chute can then be connected to the lower end of the boom chute, giving a 60- or 70-ft. pouring radius with no floor support. This combination can readily be shifted by three or four men.

Boom-and-counterweight-chute Plants.—In this type of plant, a counterweight chute 40 to 50 ft. in length and a boom chute of the same length are connected. The counterweight chute swivels on the end of the boom chute. This combination is more easily moved than the boom-chute arrangement and gives a somewhat larger operating radius.

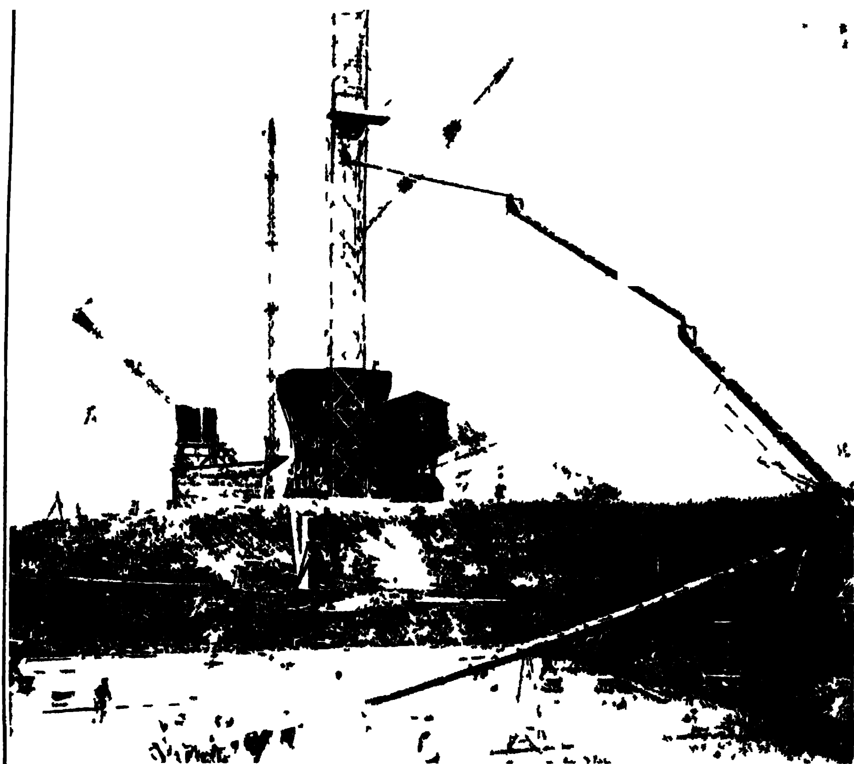


FIG. 72.—Tower plant with combination chuting arrangement, Ransome Concrete Machinery Co.

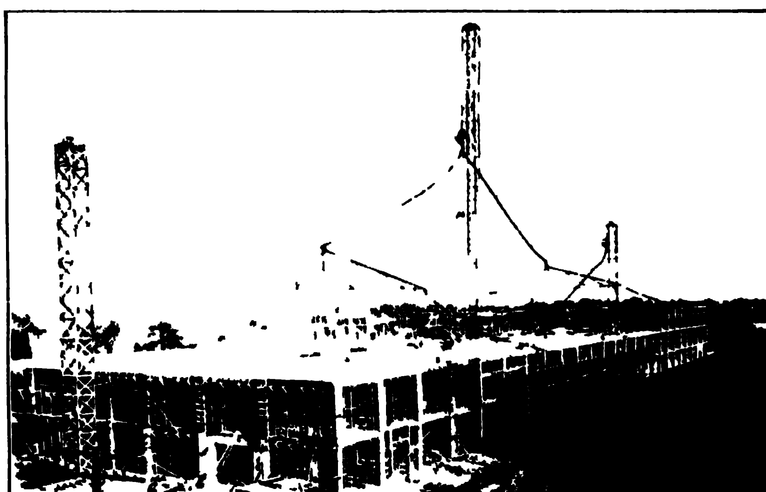


FIG. 73.—Combination counterweight and continuous line chuting plant, Insley Mfg. Co.

Continuous-line Plants.—This type of installation is used for work of limited height where concrete has to be placed at a distance exceeding 200 ft. from the mixer. This is particularly useful in certain types of low industrial buildings such as shown in Fig. 73. The chutes are hung from an overhead cable which with tall masts may be as much as 500 ft. long.

Combinations of Chuting Systems.—Combinations of the above systems are used advantageously in one way or another in order to surmount special obstacles. Among such combinations may be mentioned a re-hoisting tower which permits covering a wider area. In such a plant the concrete is distributed from the mixer and first tower through chutes to a hopper at the base of a second tower when it is again elevated and distributed throughout the work. At times, a counterweight chute can be anchored at its rear end and will thus carry a 25- or 30-ft. chute at its forward end without support. This will increase the radius of operation considerably.

WOODWORKING EQUIPMENT

By Waldo G. Bowman

20. Power Saws. Air, gasoline, or electric power saws will be found economical on any job where wood is employed to any great extent. Two types of saws are available, one a simple rotary saw mounted in a small frame and operated manually; and the other a more complete unit mounted in the form of a table. In the latter case, the motive power is mounted on a base under the table and belt connected to the saw mandrel or arbor. A rip or cross-cut saw of from 12 to 24 in. may be placed on the mandrel.



Fig. 74. Air operated handsaw, Crowe Mfg. Company, Cincinnati, Ohio.

Table band saws may be employed where the material is not of large dimensions and where irregular shapes are to be cut. Circular rip or cross-cut saws will be found more serviceable than band saws on jobs using large material in straight work.

21. Jointers.—Jointers will be found useful where many close-fitting joints are required and may be obtained as a portable unit similar in general features to the table cross-cut saw.

22. Combination Machines.—Combination machines, including all of the above units, may be obtained from a number of manufacturers and have proved their worth. A typical machine carries the following equipment: 18-in. cross-cut and rip saws, boring attachment, 6-in. cylindrical jointer, 10-in. emery wheel, saw table with adjustable gages for rip and cross-

cut work, and a 6-hp. gasoline engine. This machine has ripping ability up to 6-in. lumber and weighs 2400 lb.

23. Electric and Air-driven Boring Machines.—Portable boring machines for woodworking are most useful appliances and save much time and labor. These are described under steel-erection equipment, the same machines accommodating both steel and woodworking drills and bits.



Fig. 75.—Gasoline-powered saw rig with tilting table.

HOISTS, DERRICKS, AND SCAFFOLDS

By Waldo G. Bowman

24. Hoists.—Hoists, whether actuated by hand or by power, are devices of the highest importance in all building operations. They are ordinarilly classified by horsepower or by the number of drums employed. In addition, power shovels, cranes, pile drivers, and other pieces of construction equipment are provided with auxiliary winding drums designed to serve as hoisting means for any purpose required; and these may or may not carry a classifying name according to local usage or may simply be termed "drums," "niggerheads," or "hoists."

24a. Power for Hoists.—As is the case with power shovels, steam, the once universal and still ideal power from an operating standpoint, is being superseded for hoist operation by gasoline or electricity on building operations. Gasoline engines are at the present time used most extensively. Usually, the power unit is supplied mounted on the frame with the drums for convenience in portability and to provide any necessary counterbalancing weight. The drums may be either connected direct to the engine or driven through silent chains and gears running in oil to provide the necessary speed reduction. Wood frictions, either bare or covered with an asbestos composition to prolong their life and efficiency, are used. Extra drums can be added to all hoists to extend their field of usefulness. The method of operation of all hoists- gasoline, electric, or steam—is practically identical, so that operators have no difficulty in changing from one to another.

Small air or electric-driven single-drum hoists of about 6 hp. are coming into extended use for handling loads up to 2000 lb. and often are a great advantage over hand hoists where compressed air is available as it is on most modern construction operations. Such air hoists (Fig. 81) weigh from 300 to 600 lb. and operate on 50- to 75-lb. air pressure.

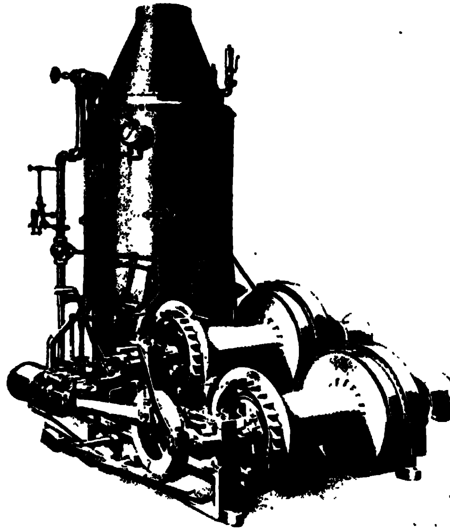


Fig. 76.—Double-drum steam hoist, Clyde Iron Works, Duluth, Minn.

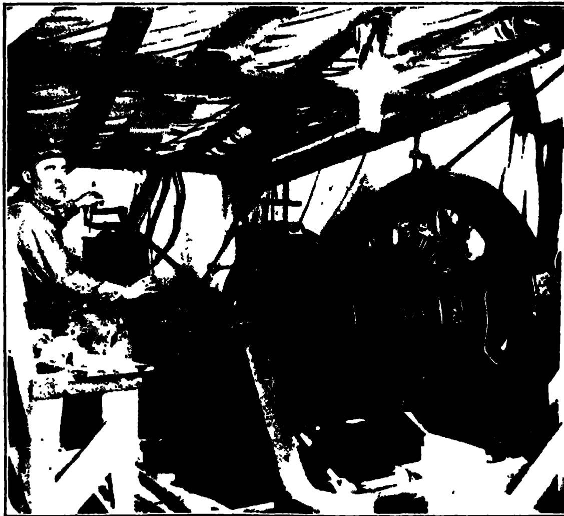


Fig. 77.—Single-drum electric hod hoist, Mundy Hoisting Engine Company, Newark, N. J.

In practically all hoists the drum is a cast-iron spool fitted with a rack at one side and a friction clutch at the other. The drum is carried loosely on a shaft to which are keyed the driving gear and the positive portion of the clutch. By means of a handle, operating through a friction screw, pin, and cross-key, the drum is pushed laterally until the two parts of the friction clutch engage. A spring placed between the drum and gear gives quick and positive release when the pressure on the friction screw is removed. A band brake, operating when the clutch is disengaged, provides means for lowering loads by gravity.

24b. Hand-operated Hoists.—Hand-operated hoists are of several types block and fall, differential pulley, winch, or crab. In the first two types, no drum is provided, the line being coiled or allowed to lie as it is hauled. With the crab and winch, a drum is pro-

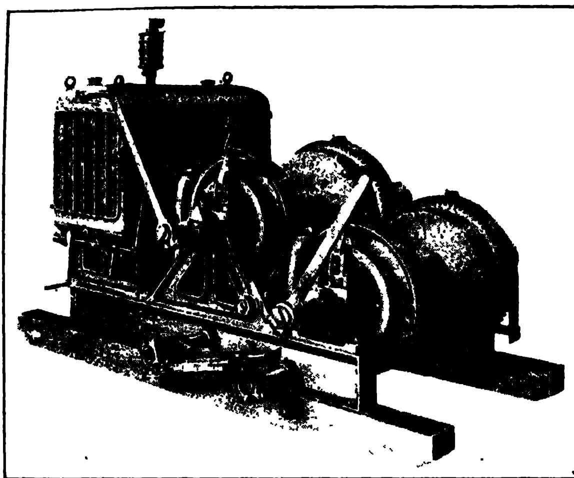


FIG. 78.—Double-drum gasoline hoist, Clyde Iron Works.

vided which is driven through gears to obtain power and speed ratios suited to the loads and the number of lines on the pulley blocks.

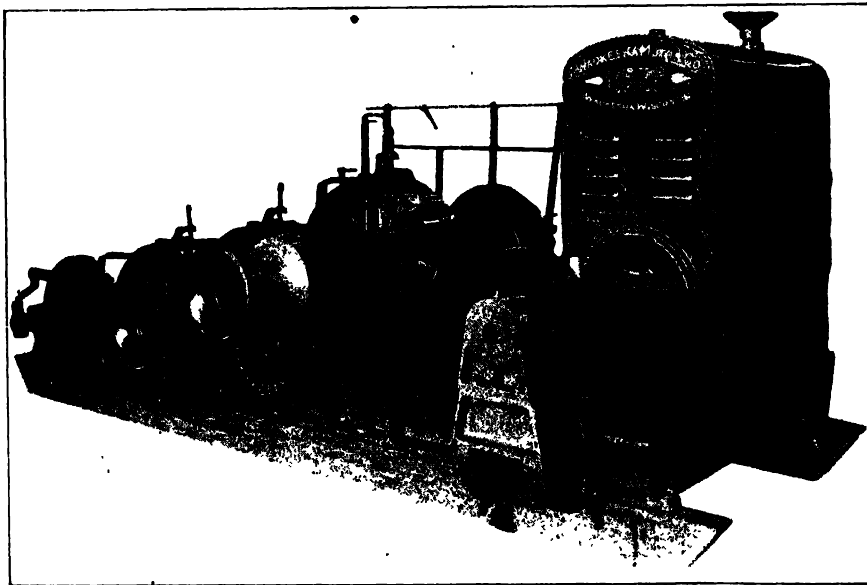


FIG. 79.—Triple-drum three-speed hoist with swinging gear; showing transmission box and silent chain drive, Mundy Hoisting Engine Company.

Hand-operated hoists are used in cramped quarters or where the load is light, though with the differential pulley loads as great as 10 tons may be handled. Differential blocks may be suspended from any convenient point and are very adaptable and convenient. In these blocks, ropes are replaced by chains which grip positively on wheels which operate the hoist through a chain of gears.

24c. Power-operated Hoists.—Hoists powered by gasoline engines or electric motors are available in sizes ranging from 8 to 100 hp. In general, the number of drums and the horsepower determine the type of service for which a hoist is adaptable. Thus, single-drum hoists from 8 to 55 hp. are ideal for hod hoists or general material elevating purposes. They have a high speed of about 500 ft. per min. The double-drum gasoline or electric hoist from 20 to 100 hp. with line a pull of from 750 to 12,500 lb. and a speed of about 175 ft. per min. is suitable for heavier tower hoisting service and when used with a swinger drum, which can be attached, is adaptable for derrick work. However, the three-drum hoist, especially when fitted with a swinger drum, is most suitable for derrick service, either for excavating with a grab bucket or for hoisting structural steel and concreting forms.

A special hoist with a three-speed sliding gear transmission (Fig. 79), similar to those used in motor trucks, has many advantages over the single-speed hoists which must be re-reaved to fit them for different kinds of service. The three-speed hoist is made in single-, double-, or triple-drum types in all sizes from 20 to 100 hp. On such a hoist the high gear can be used when hoisting light materials where speed is desired, and the lower-speed gears when hoisting heavier objects. Thus, on concrete tower work the high speed can be used to raise the bucket and the low speed to shift the sliding frames and hoppers from one floor to another. A typical speed range for a three-speed hoist is 175 f. p. m. in low, 280 f. p. m. in second, and 120 f. p. m. in high gear. The line pulls, of course, decrease as the speed increases.

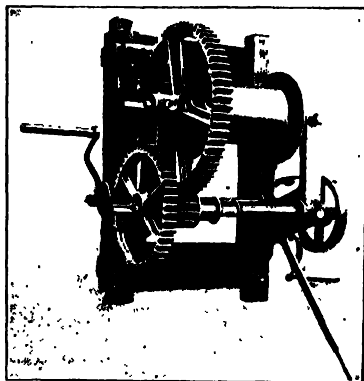


Fig. 80.—Hand crab, Clyde Iron Works, Duluth, Minn.

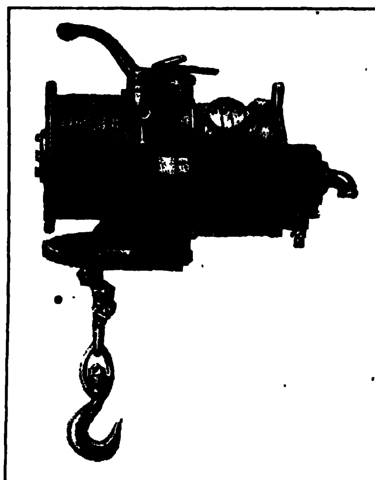


Fig. 81.—Small air hoist, Ingersoll-Rand Co.

25. Derricks.—In simple terms a derrick consists of a mast, boom, bull wheel, and means of supporting the mast. Where the mast is held in place by several ropes attached to a ring at the top it is known as a guy derrick; where two solid members placed at an angle with the horizontal are used it is a stiff-leg derrick. Mast, boom, and legs may either be solid sticks of timber or built of latticed structural steel.

A special stiff-leg derrick (Fig. 82) with full-circle swing and with the hoist mounted directly over the bull wheel has an advantage in maneuverability over the ordinary stiff leg which has only a three-fourth-circle swing. With a 55-ft. boom and a three-speed hoist equipped with a power take-off to rotate the machine, the full revolving stiff-leg can be used for all sorts of foundation work on a site 80 ft. square.

What is known as the "*Chicago boom*" (Fig. 83) is simply a boom mounted on the side of an adjoining building or to one of the columns of the structure itself. This does away with the space occupied by a free derrick and in some situations is advantageous but is not to be generally recommended.

The height of mast and length of boom and legs of a derrick will depend on the nature of the work and the space available. The main advantages of the guy over the stiff leg are full-circle swing, less ground space occupied, and ease of moving from one floor level to the next. In comparison with the rotating stiff leg, some of the advantages

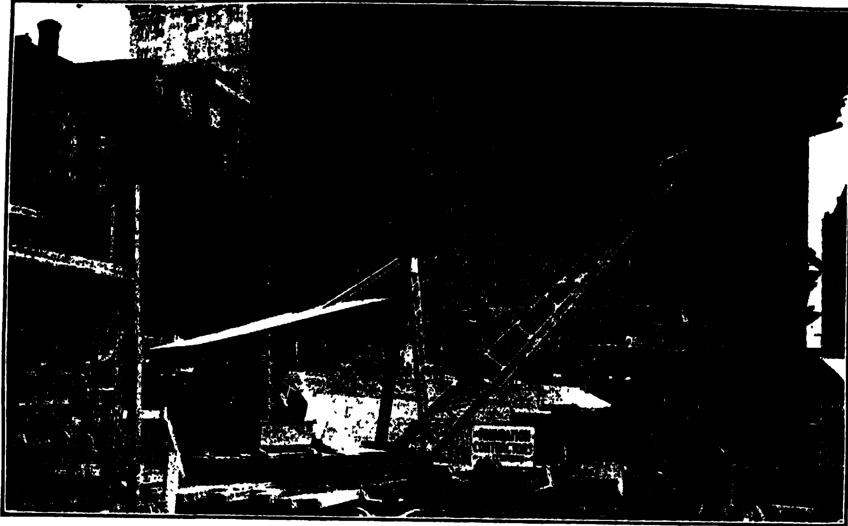


Fig. 82.—Full-rotating derrick with Mundy three-speed hoist and swinging gear.

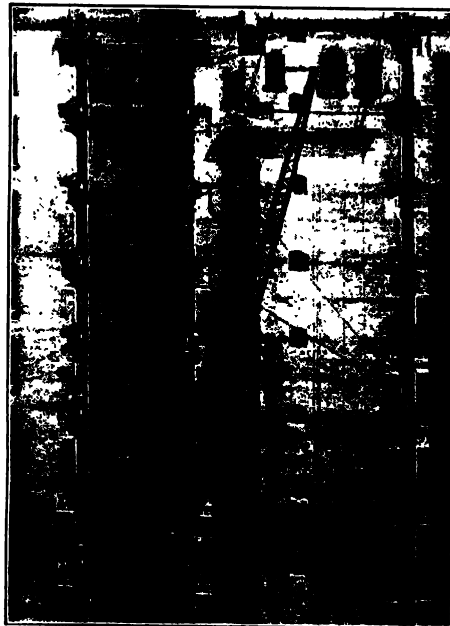


Fig. 83.—Chicago boom.

of the guy derrick are, of course, eliminated. In narrow lots, where short-length guys would have to be used, the stiff leg is generally found more satisfactory. The boom of the guy derrick is a little shorter than the mast. In the stiff-leg derrick the boom is longer than the mast. The angle of swing for a stiff leg is limited to 270 deg., while for the Chicago boom it is still further restricted to 180 deg.

The proportions of the members will vary with the nature of the work and the loads to be handled. A guy derrick to handle a 1½-cu.-yd. bucket weighing about 6 tons would have a mast of 12 × 12-in. timber not much over 50 ft. high and a 10 × 10-in. boom not over 40 ft. long. Longer lengths may be used but should be trussed or made of larger timber.

Two drums and a swinging gear, together with the power unit, comprise the usual equipment for a derrick. The swinging gear may be on a separate frame but is generally mounted ahead of the drums and attached to the same skids.

Other means of hoisting which may be classified as derricks are the "A"-frame and the gin pole. The "A"-frame derrick is made of timber in the shape of an A supported at the apex by guys. The block for the fall line is attached at the same point. It is slightly canted toward the load and is operated by a hand crab. These outfits are readily portable and are used in hoisting stones for sills, etc., and in places where it would be difficult to operate a power derrick.

A gin pole consists either of a stick of timber or of a built-up latticed mast guyed from the upper end by two or more ropes. The hoisting block and tackle is attached to the top, no boom being provided. The pole is used for erecting trusses, for handling a steam hammer, and for other purposes where a straight lift is sufficient. This pole hoist may be operated either by hand or by power. If power is used, a single-drum hoist is adequate.

26. Scaffolds.— In practically all stages of construction work, from foundations to paint, scaffolds are employed.



Fig. 84.— Hanging scaffold with double platform winches, Patent Scaffolding Co., N. Y.

Scaffolds may be either swung from some point above the working level or built up to the required level from a firm base. Either type should comply with safety laws, not only for the security of men employed on the scaffolds but also for the safety of those who may be working or passing below. In addition to the safety of the scaffold itself, guard rails strung about 4 ft. above the platform should be provided to prevent men from falling off. Footboards to prevent tools and materials from being knocked from the scaffold should be provided. In all cases where work is in progress above the men on the scaffold, overhead protection should also be provided. Heavy canvas properly supported, wire netting, or a plank platform are the means often employed.

On building jobs surrounded by sidewalks which must be kept open for the use of the public, protection must be provided in the form of a covered sidewalk bridge. Such a bridge may be built of any available material either wood or structural steel. The Patent Scaffolding Company of New York has developed a standardized steel-frame sidewalk bridge (Fig. 88) which is rented for the life of a job, or it may be purchased outright. It is claimed to be cheaper than wooden scaffolds, easier to erect, and more pleasing in architectural appearance. Each unit or bent consists of an 8-in. I-beam clamped to 4-in. steel-pipe columns. The columns are braced in the longitudinal direction by 1½-in. steel pipe and by the handrail. This steel framework is covered over with wood sheathing.

26a. Suspended Scaffolds.—Two main types of suspended scaffolds are in general use. One is that commonly used by painters, consisting of a platform supported by blocks and falls hung from iron braces at the cornices, braces which are further held in position by ropes tied back to a chimney or other firm anchorage. Scaffold irons made up of flat-rolled stock placed at each end of the scaffold support the platform and also have arms to hold a guard rail. With this type of scaffold the platform may be raised and lowered from the scaffold through blocks and falls, the free end of the line being tied around the block hook to hold the scaffold in position. With these scaffolds, actuated with a man on the platform, there is some danger of the scaffold's falling by having a rope run through the operator's hand too rapidly or by the breaking of a rope.

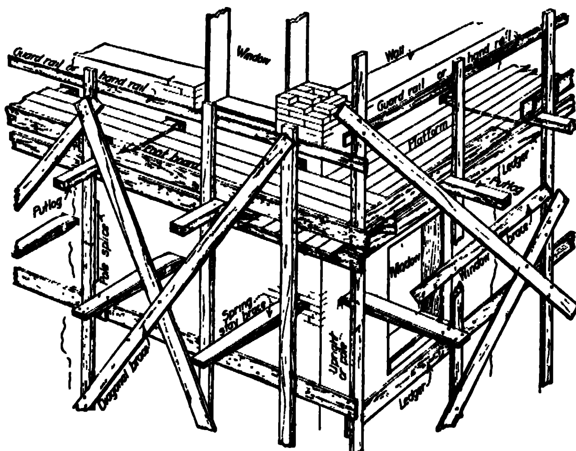


Fig. 85.—Bricklayers' pole scaffold.

A better type of scaffold, found in most building work where the loads are heavy and the time of use is considerable, consists of steel channel thrust-outs, steel ropes, drums, and built-up scaffold irons, as illustrated in Fig. 84. Small drums, either mounted on the thrust-outs or located above and operated through worm wheels and ratchets, are provided for changing the height. Of the two, the first is, in general, the better, as the control is visible to the operator so that such dangers as incomplete locking of pawls, rope-over riding the side of the drum, etc., are minimized; and inspection is much simpler, easier, and more likely to be thorough. On the other hand, the drum occupies space on the scaffold.

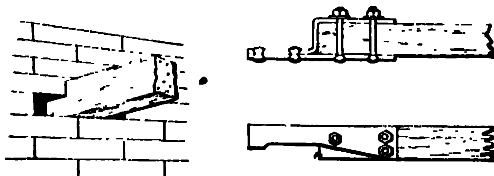


Fig. 86.—Putlogs for scaffolding.

26b. Fixed Scaffolds.—Fixed scaffolds may be divided into two main types—pole and outrigger—and in buildings up to about five stories are the ones generally used.

Pole scaffolds are so called because they are built up of poles or scantlings from a firm base, generally the ground (Fig. 85). Under this classification would come the large scaffolds used in erecting walls, etc., and the smaller types such as ladder scaffolds where the working platform is raised but a short distance, as in painting and plastering ceilings and the like. Scaffolds built up for wall work should be carefully designed for all loads and stoutly braced to prevent any tendency to collapse under side loads such as wind, etc., and should be held to the building in some manner.

Two types of pole scaffolds are found—one where the poles are run up as units, ledgers and putlogs being placed as the working platform is raised; and the other where two poles are connected together by strips nailed securely and at right angles to them. These strips are placed at distances corresponding to the required lift and with the poles form rough ladders. Ledgers are run between the strips, and the ladders are braced. This type of scaffold must be fastened to the building, which is usually done by bracing from the windows. In general, this type of scaffold is not used in heavy work but rather in cases where wall areas are to be cleaned or painted. The pole scaffold is composed of six main parts—the upright poles, ledgers, putlogs (Fig. 86), braces, spring braces, and the platform itself. The ledgers are the members which extend from pole to pole and support the outer end of the putlogs. In addition to the ledgers, diagonal bracings should be used. Putlogs support the platform and rest on the ledgers and the finished wall. Three types of putlogs are shown in Fig. 86, one all wood, the other two having one end built up of iron. Spring braces are used to hold the scaffold to the base of the wall and consist of two boards inserted in the putlog hole, with a brick placed between them. The outer ends are then nailed to the ledgers causing the inner end to spread and press against the bricks so forcibly that considerable effort is required to dislodge them.

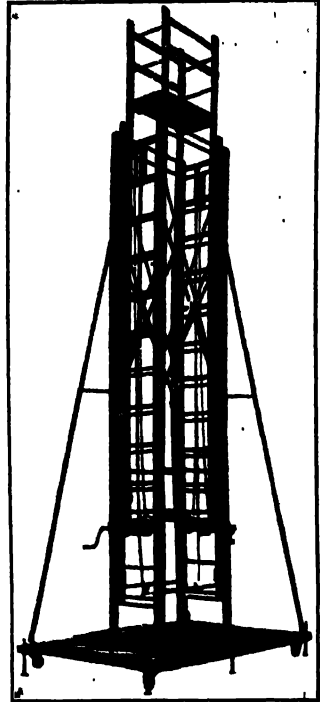


Fig. 87.—Adjustable interior scaffold, Chesebrough Whitman Co., N. Y.

Horse Scaffolds.—The height of a horse is about 48 in. Horse scaffolds may be built up by placing one horse on top of the other but should seldom include more than three horses. Such scaffolds are not suitable for heavy loads or for the storage of any amount of material. In general, they are potentially dangerous and should be avoided.

Outrigger Scaffolds.—Outrigger scaffolds are so called because the platform is supported by beams fastened to the floor or the frame of the building. This type is used where repairs are to be made at some such point above ground level that it would not be economical to build up from the ground, and where suspended scaffolds could not be used—for example, on a church steeple or the tower of a building.



Fig. 88.—Sidewalk protection during construction, Patent Scaffolding Company, New York.

STEEL-ERECTION EQUIPMENT

By Waldo G. Bowman

Tools and appliances required for the erection of structural steel depend upon the method of erection used; upon the type and size of the structures; upon the freedom with which operations can be carried on; and upon local usages and conditions.

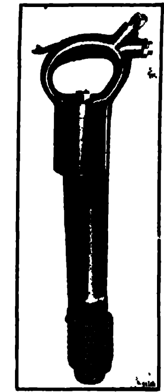


Fig. 89.—Air riveter.

First and perhaps foremost in all structural-steel erection appliances comes the use of hoisting means whereby the members may be placed in position. All of these have been treated in previous chapters of this section.

In the bolting, cutting, chipping, riveting, and welding of the various members, a variety of both ordinary and special tools are employed. Ordinary hand tools, such as hammers, chisels, punches, wrenches, tongs, etc., or small hand forges for steam rivets need no special mention. Some of the automatic tools driven by compressed air or by electricity will be described, as they come in a special and highly useful class.

27. Air Riverters.—Air riveters as used in structural-steel erection are made in many forms to meet special requirements. They comprise a shell containing the working parts, the piston or striking member, the valves, and a removable steel set for forming the head of the rivet. These air hammers (Fig. 89) are light in weight and portable. The air supply is controlled through a throttle valve which consists of a piston and poppet in combination, actuated by a trigger attachment on the handle. Several types of handles are supplied to meet various conditions, their design not changing the operation in any way. By this trigger arrangement the strength of blow may be governed by the operator from a light tap to full impact.

28. Air and Hand Dollies.—The dolly is, in effect, an anvil held against the rivet head. It may be either a long bar held in position by hand or a separate pneumatic machine (Fig. 91). The latter type will give better results, as it keeps the head of the rivet in contact and avoids



Fig. 90.—Outside and inside trigger handles for Ingersoll-Rand riveter.



Fig. 91.—Air dolly.

the jumping so common when a hand dolly is used. The hand dolly, however, is more convenient for general field use.

29. Rivet Sets.—A rivet set is a small die of tool steel fitted into the end of the riveter and held in position by spring fingers or a coiled spring. It is detachable so that change from one size or style of head to another is quickly accomplished. In operating, the set should never be lifted from the rivet head inasmuch as the coiled spring will not hold the set in the riveter, and flying from the gun it is a dangerous missile.

30. Air Chipping Tools.—Chipping tools are chisels designed to socket into the air-hammer barrel. They can be obtained in a great variety of shapes suited to any desired purpose.

Chipping with air hammers is highly efficient, since the rapidity of blows approximates continuous chipping with consequent facility in holding the tool to the work.

31. Air Drills.—Air drills are made in two types. The type shown in Fig. 92 is the one more commonly found. These machines may also be used for reaming, tapping, etc. Air drills are driven from a crankshaft actuated by pistons. The valve action is controlled by gearing from the crankshaft; and air is admitted from the supply line by turning a sleeve on the handle.

32. Electric Drills.—Portable electric drills though somewhat heavier and for a given weight less powerful than air drills give excellent results for drill sizes up to 2 in. in diameter. In these a motor through gearing drives a shaft having a hollow taper to which is fitted the drill itself or a chuck holding the drill. Electric drills are made for use with either direct or alternating current at frequencies and voltages commonly found. The weight of a drill for a 2-in.-diameter hole in steel is about 88 lb.

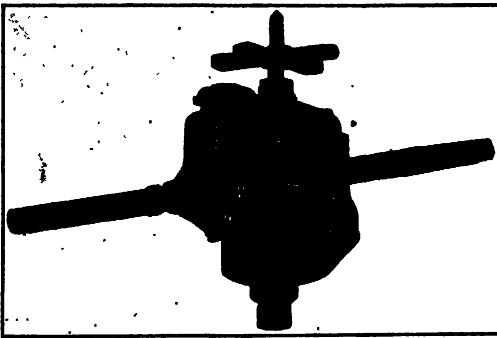


Fig. 92.—Sectional view of air drill.

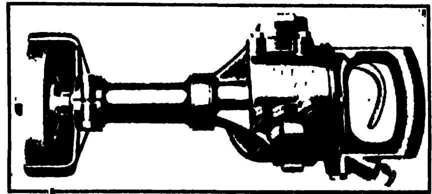


Fig. 93.—"Little David" air grinder, Ingersoll-Rand Co., N. Y.

33. Air and Electric Grinders. Air grinders (Fig. 93) and electric grinders differ from air or electric drills only in the cutting tool used which is an abrasive wheel instead of a drill. Electric grinders have an advantage over air grinders in that the speed obtainable is higher, which makes for rapid cutting.

Cutting wheels should be of a grain and hardness of material suited to the material to be cut. For structural steel, a medium-grained rather hard wheel should be used. For harder steels, a softer wheel of light grain is preferable. Carborundum, alundum, crystolon, and like abrasive materials cut more rapidly and better than emery. Microscopic examination of cuttings shows that the two materials first named cut shavings from the steel, while the last produces globules of molten metal.

34. Oxyacetylene Cutting.—Wherever steel or iron in any shape has to be cut on the job, an oxyacetylene outfit is useful. The apparatus, in general, consists of a blowpipe or torch and rubber hose lines connecting the torch to the generating unit. The generating unit as usually composed is a tank containing liquefied or compressed oxygen and an acetylene generator or tank of acetylene together with attached regulating valves. The oxygen and acetylene gas tanks are fairly portable units. The acetylene may be generated on the job, but this is a troublesome and comparatively dangerous task. The torch first preheats the metal to a white heat, after which the oxygen flame does the actual cutting. Different sizes and types of torch tips are supplied each to be used for a specified purpose.

35. Welding.—Structural steel may be welded either by the oxyacetylene process or by the electric arc. In the former process, the surfaces to be welded are placed in contact and heated by the oxyacetylene torch. When the material is at a white heat, the welding rod (which is material of the same kind that is being welded) is placed in the torch flame and melted into the white-hot metals at the point where the weld is to be made. Some roof trusses

have been welded by this process, but in building construction it has so far been mostly used for welding the lengths of service pipe together and for general blacksmith-type repair work.

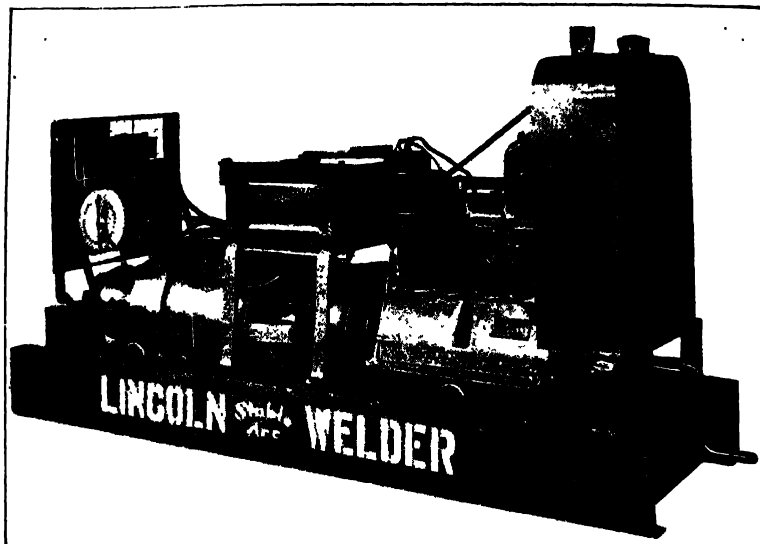


FIG. 94A.—Electric arc welder manufactured by the Lincoln Electric Company.

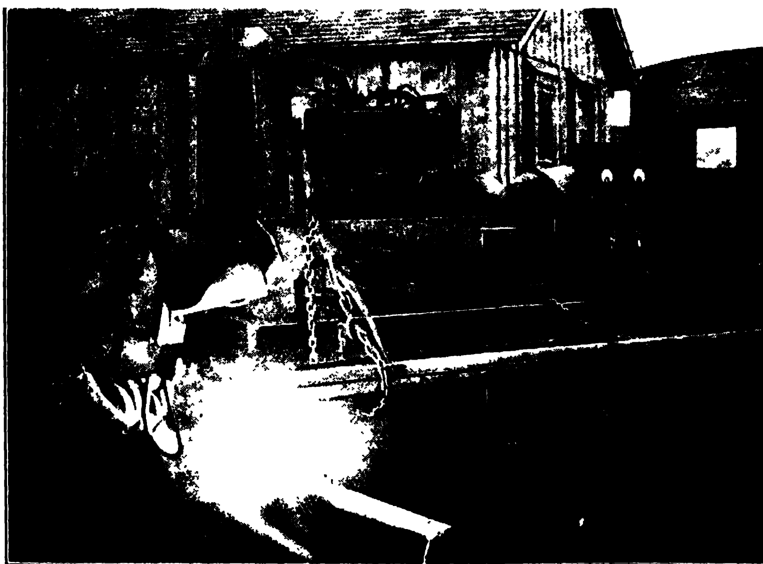


FIG. 94B.—Electric arc welder manufactured by the General Electric Company.

Electric arc welding has been used more extensively in welding structural steel than has the gas process, numerous buildings and one or two bridges having been built by the former method.

In the electric arc welding process, the metals to be welded and the welding rod are fused together by the intense heat of an electric arc. In this process, the metal to be welded forms a part of the electrical circuit. There

are two main systems of electric welding—the metallic-arc method and the carbon-arc method. In the metallic-arc method the parts to be welded are attached to the positive side of the circuit, and a metallic filler rod, either bare or coated with some sort of flux material, is attached to the negative side of the circuit. The arc is established by striking the filler rod against the work. Molten metal from the rod is deposited with the molten parent metal, and as it cools the weld is formed. It is, of course, necessary to move the melting rod downward at a uniformly continuous rate to compensate for the part that is melting away; otherwise, the arc gap will become too great for the current to jump. Direct current produces a hotter arc than alternating current, and a special type of direct-current generator is required for satisfactory welding. A voltage of 30 will maintain an arc, although a higher voltage is required to strike it. The usual current flow will range between 50 and 300 amp. The amount of voltage in most welding circuits is harmless, so that the shock from it will be slight, if felt at all.

In the carbon-arc method a graphite electrode instead of the metallic filler rod is used as the negative pole. With this method the arc supplies the heat, and the filler metal must be fed into the weld by hand from a metallic bar. The arc must be played upon one spot for a considerable length of time before the filler metal is added Carried far enough the use of a carbon electrode results in cutting.

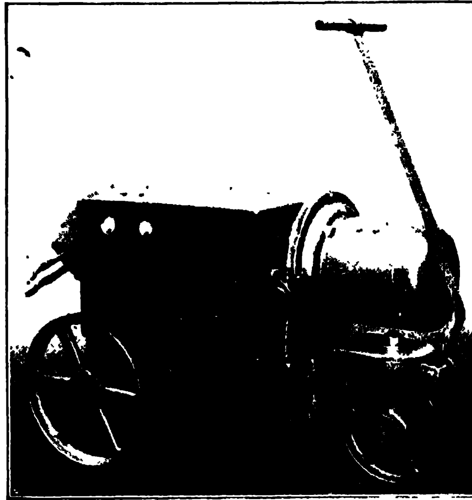


Fig. 94C.—Electric arc welder manufactured by the Westinghouse Electric & Manufacturing Company.

MISCELLANEOUS EQUIPMENT

By Waldo G. Bowman

36. Air Compressors.—The uses of compressed air in building construction are so varied and cover such a prolonged period, extending from placing foundations, as in sinking pneumatic caissons, through steel erection, and even to finished painting, that the selection of air compressors and the installation of the air-distributing system should be planned most carefully. A wide choice of compressor equipment is available.

First consideration should be given to a portable compressor because of its ease of installation and the flexibility which it lends to the layout of the construction plant. Portable compressors are available in sizes having displacements from 100 to 300 cu. ft. of free air per min. Either electric motor or gasoline-engine power units are available. In some of the machines power transmission is through a clutch, while others are direct connected. On one machine the cylinders of both the gasoline engine and the compressor are attached to the same crankshaft. The mountings are usually four-wheel trucks equipped with either steel or rubber tires. Should the single portable compressor be too small for the air requirements, any number of units may be connected in series discharging into a common drum.

Stationary plants are often necessary. These can be obtained in practically any capacity. Such plants may be either steam or electric motor operated. They require concrete foundations, a housing of some sort, and a rather complex layout of piping. All portable compressors deliver from 90 to 100 lb. per sq. in., while the discharge pressures of stationary machines suitable for building-construction requirements vary from 15 to 500 lb. per sq. in.

Compressors of the smaller sizes are built single stage, all compression taking place in one cylinder. The larger sizes are two or three stage, having two or three cylinders, each of which raises the pressure a certain part of the final value.

Compressed-air engineering represents a large field in itself, and comprehensive data are beyond the space limitations of this handbook. Such organizations as the Sullivan Machinery Company in Chicago and the Ingersoll-Rand Company and the Chicago Pneumatic Tool Company in New York City are specialists in the field. Those interested should consult these companies as well as standard textbooks on the subject.

37. Air-painting Equipment.—Painting by compressed air has recently come into quite general use. In this work, air under pressure is fed through a rubber hose to a metal paint

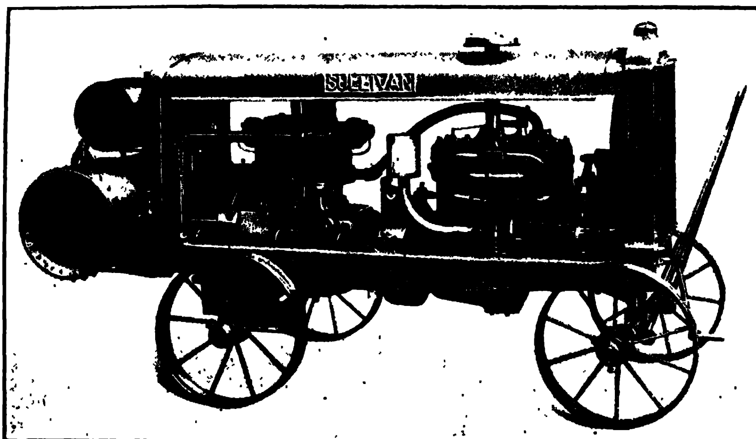


Fig. 95.—Portable compressor, Sullivan Machinery Company.

container with a control head. Air pressure is admitted at the top of the container and forces the paint through a strainer up to the control head and then through a rubber hose to the "gun." The metal container is a tank of 3 to 15 gal. capacity. The gun or painting nozzle is shaped like an ordinary pistol with a trigger to control the supply of paint and air. The handle carries connections for the air and paint lines. Where desired, the gun may be mounted on a



Fig. 96.—Painting with compressed air, Spray Engineering Co., Boston, Mass.

long pole enabling the operator to paint in places where ladders or scaffolding would otherwise be required. The weight of the 5-gal. unit is about 50 lb., and that of the larger sizes greater in proportion.

38. Surfacing Machines.—Special machines for finishing the surface of concrete either in floors or walls and for removing form marks may be operated either by air or by electricity. Surfaces may also be treated by rubbing by hand with carborundum, washing with a dilute

acid, or brushing with a stiff wire brush. Each of these methods has its place, but better and cheaper results can be obtained with a mechanical device.



FIG. 97.—Compressed air painting equipment, Spray Engineering Co., Boston, Mass.

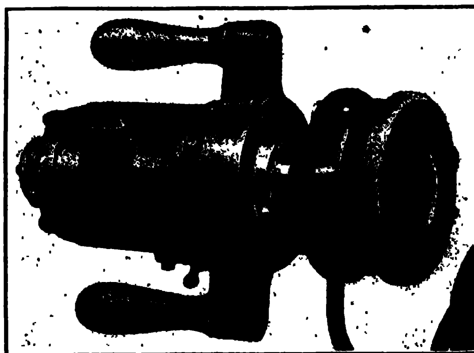


FIG. 98.—Electric rotary concrete surfacer.

Some air surfacers are similar to air hammers but strike a much lighter blow. A variety of tools arranged to socket in the device are used for different purposes. Where it is desired to have a pebbled surface, an air surfacer of this type will be found particularly effective. The other type of surfacer is a rotary model; it may also be oper-



FIG. 99.—Air-operated rotary concrete surfacer, Ingersoll-Rand Company.



FIG. 100.—Applying "Gunite" with cement gun, Cement Gun Company, Allentown, Pa.

ated either by compressed air or by electricity. In Fig. 98 is shown one operated by electricity, while Fig. 99 shows an air-operated rotary surfacer in use. These surfacers consist of a motor and a tool using different types of teeth or grinding discs which revolve at a high speed and chip or grind the surface to a finish.

39. Stucco and Plastering Machines.—Special machines for applying stucco and plaster have been developed, which are claimed by the makers to give better and more lasting results

than hand methods. Two types of machines are available, one which impels the material mechanically against the wire or lathe, and the other which places the material by compressed air. The latter equipment is the most used. This equipment is known as the "cement gun," (Fig. 100). In operation the materials are premixed dry and placed in a drum. Air pressure is then applied above, the feed being regulated by a rotating wheel actuated by an air motor within the casing. The dry mix is thus forced through a hose to the point of application where it is mingled with a fine spray of water delivered through a parallel hose line outside the casing. Material produced by this device is known as "gunite" and has the merit of being very hard and dense.

40. Lighting Equipment for Construction Work.—More and more construction work is being carried on 24 hr. per day, involving the use of artificial light. Although gas, oil, and electricity are all available for this use, electricity and acetylene gas are the most used.

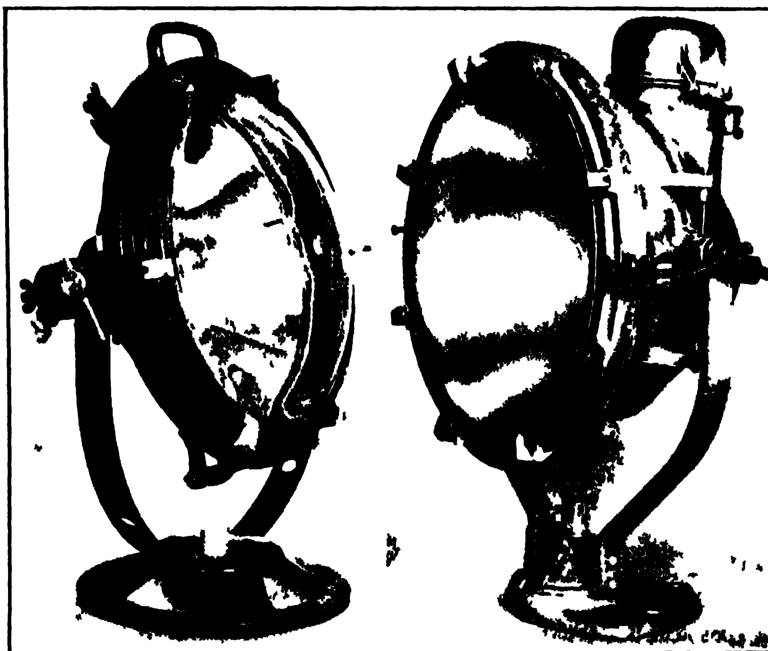


Fig. 101.—Two types of electric floodlight for night building work, General Electric Company.

When using electric lighting, the apparatus for different kinds of construction work varies greatly, although an intensity of 3- to 4-ft. candles usually will give sufficient light. As a general rule, a beam wide enough to cover the area to be floodlighted will give satisfactory results. The size of unit to be used depends upon three factors—the area to be lighted, the character of the surroundings, and the color of the objects.

The portable carbide light (Fig. 102) is a type of acetylene-gas light. Owing to its light weight and large candlepower, it is used extensively. The light, however, is a concentrated one, and the apparatus requires frequent charging and cleaning. It consists of a burner, feed pipe, and generator. The units are made in various sizes to meet different requirements.

41. Pipe and Bar Threading Machines.—Threading machines both for pipes and for bars should be supplied on all jobs of importance. The smaller hand dies and taps form a usual and necessary part of the fitting equipment on smaller work. Pipe-threading machines are supplied in a number of sizes and have a wide range of capacity. These machines are driven by gasoline engines or electric motors either directly or through belts. They may be obtained

using either a solid die up to about 2-in. size of pipe or with separate jaws of 2 or 4 pieces for larger sizes of pipe. Bar-threading machines are similar to those used for pipe threading, the difference being in the size and shape of the teeth of the die. Bar dies also are cut without taper threads. Bolts and bars up to 4 in. can be threaded in these machines, and either right- or left-handed threads cut.

42. Equipment for Winter Construction.—Building construction is rapidly becoming a year-round business. As winter construction becomes more universal, equipment needs will increase. At present, tarpaulins are used extensively to enclose the building in which a moder-

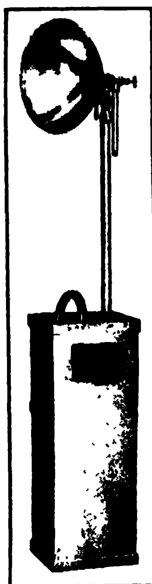


Fig. 102.—Carbide light, The Alexander Milburn Co., Baltimore, Md

ate temperature is maintained by salamanders. Most of these burn coke at the present time, but several gas salamanders are available. Thawing torches burning kerosene are in general use for maintaining frozen pipe lines. They may also be arranged for heating an enclosure holding concrete aggregates. Equipment similar to the thawing torch is available for attachment to a concrete mixer drum to maintain average temperatures of 60°F. One type of such equipment is manufactured by Hauck Manufacturing Co., Brooklyn, N. Y. Boilers and hot-water heaters, of course, play a part in winter concreting work. However, there is a large field open for development of equipment for winter, and such things as enclosed or heated concrete chutes, special water heaters, and enclosed hoisting towers will soon be necessary.

SECTION 7

BUILDING MATERIALS

TIMBER

By Henry D. Dewell

Trees may be divided into two main divisions—*exogen* and *endogen*. The first division comprises those trees in which the wood is arranged in concentric bands or layers. This construction results from each year's new growth of the tree forming an approximate cylinder of new wood outside of the previous old growth cylinder. The second class of trees, the endogen type, embraces the palms, bamboos, and other trees in which the wood is not arranged in bands or rings.

All timbers used in building construction in North America may be said to fall under the exogen class. Two subdivisions of the exogen trees are recognized—viz., (1) conifers, sometimes called softwoods, and (2) non-coniferous, dicotyledons, or hardwoods. The terms "softwood" and "hardwood" are not correct, as many of the coniferous timbers are hard, and some of the non-coniferous woods are comparatively soft.

In the class of coniferous trees falls the larger portion of the structural timbers, the longleaf yellow pine, shortleaf yellow pine, Douglas fir, white pine, spruce, hemlock, cypress, redwood, etc. Under the non-coniferous, or hardwoods, are classed the oak, ash, elm, maple, walnut, hickory, etc.

1. General Characteristics of Timber.—The cross section of a tree of the exogen type shows on the outside the bark, and, in the interior, a series of concentric rings, those next to the bark being lighter in color than the interior. This outside zone of rings is termed the *sapwood*, as contrasted with the darker interior portion, which is called the *heartwood*.

The sapwood is the living portion of the tree. The heartwood, on the other hand, has ceased to grow, and is only of structural importance to the tree. Sapwood is, however, structurally as strong as heartwood, except in the case of old, overmature trees.

The rings of growth are termed annual rings, since a new layer of wood is formed each season. Each annual ring is divided into two parts, the inner ring being softer and lighter in color than the outer ring. The inner ring is termed the spring wood, being formed in the spring of the year, while the outer, harder, and darker ring is the summer wood. The annual rings thus form a record of the age of the tree.

The general structure of wood is cellular, the cells, or wood elements being in the nature of minute tubes, with interior cavities called lumina. These elements vary in size and shape; and different arrangements of cells characterize different trees. Upon the character and arrangement of the wood cells, and the nature and quantities of the compounds associated with them depend the physical qualities of the timber. Wood elements are classified as wood fibers, tracheids, vessels, pith ray cells, and wood-parenchyma fibers. In the walls of the wood elements are openings, covered by thin membranes, known as "pits," these pits being further classified as "simple pits" and "bordered pits." The pits serve to transmit water between the wood cells.

In the coniferous or softwood trees, the tracheids (and in the non-coniferous or hardwood trees the wood-fibers) are the elements of most importance; these give the mechanical strength of the tree. The tracheids and wood fibers run parallel to the length of the tree, so that they appear in section in a cross section of the tree.

Pith rays are cells that lie in horizontal planes, and extend radially from the center of the tree to the outside, connecting the vertical elements. These pith rays, also called "medullary rays," have as their main function the transmission and storage of food. Pith rays are plainly visibly in many timbers, as for example, oak. In this latter wood, they give the pleasing appearance in "quartered" or "quarter-sawn" oak.

The mechanical properties of timber are affected vitally by the arrangement, as well as by the character, of the wood elements. Since the wood elements, as the tracheids and the wood-fibers, are vertical, most woods are

comparatively easy to split. On the other hand, the pith rays tend to hold the vertical wood elements together and thus lessen the tendency to split.

When the annual rings are wide, the timber is said to be "coarse-grained;" and conversely, when these rings are narrow, the timber is said to be "fine-grained." Normally, the fibers and tracheids are parallel to the axis of the trunk or limb of the tree. Such a condition gives "straight-grained" timber. In many cases, the fibers may be twisted or they may run in a spiral direction giving the condition termed "cross-grained" timber.

The junction of the limb and stem (or trunk) forms the knots found in all structural timber. "Dead" or "loose" knots are formed by the stubs of broken or decayed limbs, the growth of the tree eventually covering these stubs.

2. Effect of Composition on Mechanical Properties of Timbers.—The chemical composition of wood consists mainly of cellulose and other materials designated as lighin. There are also present certain other substances, as water and resin.

The weight of wood depends: (1) on the amount of wood substance in the cell walls, and (2) on the amount of water contained in the wood. In green wood the second factor is of the greater importance. The water is contained in the substance of living cells, saturates the walls of all cells, and more or less fills the cavities of all lifeless cells, fibers, and vessels. Sapwood contains the most water.

The rate at which the water evaporates from timber depends upon the structure of the wood, and also upon the size and shape of the stick. High temperatures accelerate the drying of timber, even in humid atmosphere. When timber dries, the cell walls of the wood-elements shrink. The wood-elements decrease in cross section, but remain approximately of the same length. This phenomenon explains the shrinkage in cross section of any piece of unseasoned or green timber, and the approximate absence of shrinkage lengthwise. Since the wood cells in the same tree vary in thickness, unequal shrinkage takes place, resulting in strains which tend to split and warp the timber. Again, the ends of a stick of green timber dry faster than the interior portions, producing cracks in the ends of such timbers. Such tendency to crack is known as "checking." It is customary in lumber yards to nail strips of wood across the ends of wide planks or boards, in order to prevent the ends from checking. The same tendency to check exists in the sides of timbers, due to the exposed surfaces drying faster than the interior.

The shrinkage of the pith rays is one of the causes of the longitudinal shrinkage of timber, and the greater the number of pith rays, the greater the longitudinal shrinkage.

A log shrinks tangentially to the annual rings much more than radially, since in a tangential direction the cells of the summer wood which are subject to greater shrinkage than the spring wood are continuous across the width of board, but are interrupted in a radial direction by the rings of the spring wood. This tangential shrinkage leads to permanent checks. The difference in shrinkage, as measured tangentially and radially to the annual rings, explains the different behavior of lumber cut tangentially, radially, quartered, etc.

The following table gives the approximate shrinkage in width of timber, drying in open air:

APPROXIMATE LATERAL SHRINKAGE OF TIMBER DRYING IN OPEN AIR

	Percentage of width
1. All light conifers (soft pine, spruce, hemlock, cedar, cypress)	3
2. Heavy conifers (hard pine, red Douglas fir, tamarack, yew), honey-locust, box elder, wood of old oaks	4
3. Ash, elm, walnut, poplar, maple, beech, sycamore, cherry, black locust	5
4. Basswood, birch, chestnut, horse chestnut, blue beech, young locust	6
5. Hickory, young oak, particularly red oak	Up to 10

Shrinkage of timber is a very troublesome factor to deal with in the design and construction of details. Fully seasoned timber, unless kiln-dried lumber is purchased, is almost impossible to obtain, and consequently some shrinkage is almost certain to occur. This shrinkage will cause joints to open, washers under bolts and nut heads to become loose, settlement of floors, etc. It is exceedingly important to recognize the probability of shrinkage and to design details that will be as free as possible from the effects of such shrinkage.

Season checks are always unsightly but in interior work they are not generally serious from a structural standpoint except in the case of beams and girders where the unit longitudinal shearing stress is high. In such a case, season checks near the ends of the beam reduce the effective area to resist longitudinal shear. In construction exposed to the weather, season checks permit moisture to collect resulting in decay of the timber.

3. Effect of Seasoning on Strength of Timber.—The general effect of seasoning timber, if such seasoning is properly done, is to increase the strength of the timber, especially in regard to the strength of the timber in bearing across the grain. Tests have shown the percentage of increase in strength to vary from about 2 to 35% depending on various conditions such as kind of timber, test specimen, seasoning, kind of test, etc.

4. Methods of Seasoning Timber.—The most satisfactory method of seasoning is air-seasoning, or the exposure of the green timber to the drying action of natural air currents, the timber being protected from the weather. Lumber to be thus properly seasoned must be protected from rain, piled on level, firm foundations well off the ground, supported at frequent intervals in its length, and "stuck"—that is, each layer of boards separated from the adjoining layers by strips of timber. The boards in each layer should be separated from one another. This method of piling allows the air to circulate freely around each stick of timber.

Air-seasoning takes time—usually many months in order to thoroughly season the timber. For this reason certain classes of lumber, as flooring, ceiling, etc., are commonly kiln-dried, that is, exposed to high temperatures in a drying kiln. Kiln-drying must be properly done, else the timber will be brittle. Careful regulation of the heat, avoidance of extremely high temperatures, prevention of draughts of outside air, and the use of steam baths before drying are factors tending to reduce the tendency to brittleness.

5. Effect of Defects on Strength of Timber.—Defects, such as knots, cross-grain, wind shakes, etc., decrease the strength of timber. Knots are always co-existent with cross or diagonal grain in the immediate vicinity of the knot. In former years, the effect of a knot was considered most serious only when the timber was subjected to tension. It has been proved, however, that knots vitally weaken the timber in compression, due to the variation of the timber fibers around the knot from their normal direction.

Minor defects, such as pitch pockets, sap stain, etc., are of no consequence structurally.

6. Deterioration of Timber. Mechanical deterioration of timber occurs from continued use. Flooring will wear out, railway spikes will become loose in the ties, and screws subject to continued "working" will enlarge their holes in the wood and pull out. The probable deterioration due to wear and tear can be fairly accurately foreseen.

6a. Deterioration Due to Age.—In building construction, timber properly protected from the weather and from dry rot will not deteriorate with age, and in many cases increased strength may result.

6b. Deterioration Due to Decay.—The decay of all timber in building construction may be said to be due to the presence and action of bacteria or fungi. Without going into a discussion of the nature and action of such fungi, the conditions conducive to decay should be realized. These are the presence of a certain amount of air, heat, and moisture. Timber so situated that it will be subject to a free circulation of air at all times will not rot. Timber completely and permanently immersed in water or timber buried deeply without access to any air will not decay. On the other hand, timber alternately wet and dry will be subject to decay. The danger of dry rot in timber joists so set in masonry that free circulation of air cannot occur is well known. Timber in contact with the soil and set in close proximity to the ground in exterior walls will decay. In this connection, the danger of infection of otherwise sound timber from diseased timber should be recognized. In many instances infected timber is brought upon the job from the lumber yard. Only the most careful inspection can prevent such a circumstance, and the only recourse should be the rejection and removal of each affected stick unless by cutting off to safely remove all vestige of "date" the shortened stick may be made available.

Certain timbers, as cedar and redwood, are very resistant to the action of fungi.

6c. Deterioration Due to Animal Life.—In timber exposed to sea water, deterioration may occur from marine life, as the teredo and the limnoria; in the case of land structures, certain wood borers, as the beetles and termites, destroy timber. Protection against destruction from marine life must be given by the designer of timber structures; protection of timber from deterioration due to land life is properly the function of the forester and horticulturist.

The use of wood in a territory which is infested with termites requires special provision in the constitution of the building.

7. Treatment of Timber to Prevent Decay.—The prevention of decay in timber should be given as careful consideration by the structural designer as is the strength of a joint. Details of design should be so drawn that the timber is protected from the weather and from moisture, has no contact with the ground, and has access to circulation of air. Unseasoned timber should not be painted. The presence of an air-excluding film of paint around a green stick of timber is almost certain to result in dry rot. The underpinning of a building should be well ventilated, Green lumber should not be used for flooring or other tightly driven work. The ends of floor joists when embedded in masonry walls should have space around them to give access to air. Contact faces of timber to timber, and timber to metal, may well be painted with a good wood preservative.

When further measures than good design are required to prevent decay of timber, treatment by preservatives must be resorted to. Two methods are used: (1) impregnation of the timber with the preservative, and (2) brush or surface treatment of the timber.

The most common wood preservatives used are creosote, zinc chloride, copper sulphate and mercury chloride, and combinations of these. Of the above, creosote and zinc chloride are probably used most extensively.

In the impregnation process, the timber is first treated by drying or steaming, and then subjected to a bath of the preservative under pressure. The impregnation process is much more effective than surface treatment, and is ordinarily done at specially designed plants.

The surface treatment of timber with wood preservative is accomplished by painting the timber with the preservative, or by dipping the timber in an open bath of the preservative. This work is done on the job. Timber to be thus treated should be seasoned and dry, otherwise the treatment is more or less ineffective. The preservative should be heated. Dipping is far preferable to painting. All timber dipped should remain in the hot liquid at least 15 min. An advantage is claimed by some experimenters for an alternate soaking in hot and cold preservative. For brush treatment, at least two surface treatments with hot preservative are necessary, and three are to be advised.

8. Sawing of Timber.—Boards and planks are ordinarily cut tangentially,—that is, tangent to the annual rings of the log. This method is known as flat sawing, and the boards or planks are said to have flat grain, bastard grain, or to be slash cut.

In quarter-sawing the logs are cut into quarters, and then sawed across the annual rings. This method is also known as rift sawing, and the material thus cut is said to have edge grain. Quarter-sawing gives the beautiful graining seen in quarter-sawed oak and similar timbers. Edge-grained lumber also shrinks and warps less than flat-sawed lumber, does not sliver, and gives greater resistance to wear, as in vertical-grain flooring.

Timbers in which the heart of the tree is enclosed in the cross section are said to be "boxed-hearts." Such timbers will check deeply on all sides, with radial checks extending deeply into the section.

9. Classification of Lumber.—The following has been extracted from the U. S. Department of Commerce Simplified Practice Recommendation No. 16, *Lumber*, printed in 1926, and agrees with the American Lumber Standards.

9*a*. Softwood-lumber Classifications.—For the purposes of simplification of sizes and grades and of equalizing, among species used for similar general purposes, the grades of a similar name, lumber shall be classified by principal uses into (*a*) yard lumber, (*b*) structural timbers, (*c*) factory or shop lumber.

Use Classification

Lumber is the product of the saw and planing mill not further manufactured than by sawing, resawing, and passing lengthwise through a standard planing machine, cross cut to length and matched.

Lumber is classified as (*a*) yard lumber, (*b*) structural timbers, and (*c*) factory or shop lumber. Different grading rules may apply to each class of lumber.

(*a*) *Yard Lumber*.—Lumber that is less than 6 in. in thickness and is intended for general building purposes. The grading of yard lumber is based upon the use of the entire piece.

(b) *Structural Timbers.*—Lumber that is 6 in. or over in thickness and width. The grading of structural timbers is based upon the strength of the piece and the use of the entire piece.

(c) *Factory or Shop Lumber.* Lumber intended to be cut up for use in further manufacture. It is graded on the basis of the percentage of the area which will produce a limited number of cuttings of a specified or a given minimum size and quality.

Size Classification

Yard Lumber

(a) *Strips.*—Yard lumber less than 2 in. thick and under 8 in. wide.

(b) *Boards.*—Yard lumber less than 2 in. thick, 8 in. or over in width.

(c) *Dimension.*—All yard lumber except boards, strips, and timbers—that is, yard lumber 2 in. and under 7 in. thick and of any width.

1. Planks: Yard lumber 2 in. and under 4 in. thick and 8 in. and over wide.
2. Scantlings: Yard lumber 2 in. and under 6 in. thick and under 8 in. wide.
3. Heavy joists: Yard lumber 4 in. and under 6 in. thick and 8 in. or over wide.

Structural Timbers

(d) *Timbers.*—Lumber 6 in. or larger in least dimension.

Manufacturing Classification

Manufactured lumber is classified as (a) rough, (b) surfaced, and (c) worked.

(a) *Rough Lumber.*—Undressed as it comes from the saw.

(b) *Surfaced Lumber.*—Lumber that is dressed by running through a planer. It may be surfaced on one side (S1S), two sides (S2S), one edge (S1E), two edges (S2E), or a combination of sides and edges, (S1S1E), (S2S1E), (S1S2E), or (S4S).

(c) *Worked Lumber.*—Lumber which has been run through a matching machine, sticker, or molder. Worked lumber may be (1) matched, (2) ship-lapped, or (3) patterned.

1. Matched lumber: Lumber that is edge dressed and shaped to make a close tongued-and-grooved joint at the edges or ends when laid edge to edge or end to end.
2. Ship-lapped lumber: Lumber that is edge dressed to make a close rabbeted or lapped joint.
3. Patterned lumber: Worked lumber that is shaped to a patterned or molded form.

9b. Yard Lumber.—The term "yard lumber" as here used means lumber that is manufactured and classified into those sizes, shapes, and qualities required for ordinary construction and general-purpose uses (heavy timbers for structural purposes, softwood factory lumber, hardwood factory lumber, and other special-use materials are not considered yard stock).

Grade Standards

On the basis of quality, yard lumber is divided into two main divisions: (a) select lumber and (b) common lumber. These are again divided into two classes—select lumber into (1) that suitable for natural finishes and (2) that suitable for paint finishes; common lumber into (1) that which can be used without waste and (2) that which permits some waste. Each of these four classes is further divided into quality classes or grades.

Select Lumber

Lumber which is generally clear, containing defects limited to as both size and number and which is smoothly finished and suitable for use as a whole for finishing purposes or other uses in which large, clear pieces are required, shall be considered *select lumber.*

Two classes shall be recognized. The first shall be suitable for natural finishes. The second class permits similar defects and, in addition, blemishes of somewhat greater extent than those of the first class but of a type which can be covered by paint.

Grade names: A, B, C, and D.

Common Lumber

Lumber containing numerous defects and blemishes which preclude it from use for finishing purposes but which is suitable for general utility and construction purposes shall be considered *common lumber.*

Two general classes shall be recognized. The first shall be suitable for use as a whole for purposes in which surface covering or strength is required. Defects and blemishes permitted in this class must be sound. The second class permits very coarse defects which may cause waste in the use of the piece.

Grade names: No. 1 common, No. 2 common, No. 3 common, No. 4 common, and No. 5 common.

Dimension grade names: No. 1 common, No. 2 common, and No. 3 common.

Basic-grade Classifications for Yard Lumber

Total products of a typical log arranged in series according to quality as determined by appearance	Select Lumber of good appearance and finishing qualities	Suitable for natural finishes	Grade A: Practically free from defects
			Grade B: Allows a few small defects or blemishes
		Suitable for paint finishes*	Grade C: Allows a limited number of small defects or blemishes that can be covered with paint
			Grade D: Allows any number of defects or blemishes which do not detract from a finish appearance, especially when painted
	Common Lumber containing defects or blemishes which detract from a finish appearance but which is suitable for general utility and construction purposes	Lumber suitable for use without waste	No. 1 common: Sound and tight knotted stock. Size of defects and blemishes limited. May be considered water-tight lumber
			No. 2 common: Allows large and coarse defects. May be considered grain-tight lumber
		Lumber permitting waste	No. 3 common: Allows larger and coarser defects than No. 2 and occasional knot holes
			No. 4 common: Low-quality lumber admitting the coarsest defects, such as decay and holes
			No. 5 common: Must hold together under ordinary handling

General Provisions

The grading of lumber cannot be considered an exact science, because it is based on a visual inspection of each piece and on the judgment of the grader. The provisions of these specifications, however, are sufficiently explicit to establish 5 % below grade as a reasonable variation between graders.

Except in dimension, the grade of yard lumber, rough or surfaced two sides, shall be determined from the better or face side of the piece, and lumber which is surfaced one side only shall be graded from the surfaced side.

The rules for yard lumber prescribe the number and extent of defects and blemishes permitted in the poorest pieces admissible in each grade.

The number of defects and blemishes permitted varies as the area of the piece to be graded increases or diminishes in respect to the standard size specified, but the size of the defects must not exceed that allowed by the grading rules.

When defects or blemishes, or combinations thereof not described in these grading rules are encountered, they will be considered as equivalent to known defects according to their damaging effect upon the piece in the grade under consideration.

Material shall be considered vertical grain when the rings (so-called grain) form an angle of 45 deg. or more with the surface of the piece. When the angle becomes less than 45 deg. at any point, the material shall be known as flat (slash) grain.

Mixed grades other than the two highest recognized grades for each species, not specifying the proportion of each grade, are not American Standard grades.

9c. Structural Lumber.—See Appendix F, for detailed specifications for structural lumber.

Grades and Classifications

Grades: (*a*) Dense select, (*b*) select, and (*c*) common.

Uses: (*a*) Joist and plank (joists, rafters, scaffold plank, factory flooring, etc.), (*b*) beams and stringers (beams, girders, stringers, etc.), and (*c*) posts and timbers (posts, caps, sills, timbers, etc.).

The "general" requirements for structural lumber and the methods of selecting southern pine and Douglas fir for close grain (select grade) and for density (dense select grade) are given in Appendix F.

9d. Softwood Factory and Shop Lumber.

General Provisions

The grade of factory lumber shall be determined by the percentage of the area of each board or plank available in cuttings of specified sizes and qualities.

When lumber is crooked, bowed, cupped, or twisted, the cuttings must be so laid out as to be flat and straight along the edges.

Board measurement shall be used in measuring factory lumber. When measured with a board rule, pieces measuring to the even half foot shall be alternately counted as of the next higher and the next lower surface foot; fractions below the half foot shall be dropped, and fractions above the half foot shall be counted as of the next higher foot. To determine the board-foot contents of material thicker than 1 in., the surface measure should be multiplied by the nominal thickness in inches and fractions of an inch.

The board measurement of dressed factory lumber of standard and extra-standard size shall be based upon the corresponding standard dimensions of rough green lumber.

Factory Plank

The grade of softwood factory boards or plank shall be determined from the poor face, although the quality of both sides of each cutting must be considered.

In determining the percentage of door cuttings, consideration must be given to the fact that planks are to be ripped full length before cross-cutting, in such manner as will yield the highest grade and largest percentage of door cuttings, except in such cases where planks will yield a higher value by first being cross-cut for rails. In instances where stock is cross cut for rails and some of the stock so obtained contains stiles or muntins or top rails, which can be obtained by ripping this cross-cut stock, the door cuttings so obtained may be figured in when determining percentages.

Basic-grade Classification for Softwood Factory Plank

Factory plank Factory lumber graded with reference to its use for doors, sash, and other cuttings	Factory clears Upper grades of factory plank containing a high percentage of best-quality cuttings.	Nos. 1 and 2 clear factory: Lumber, practically clear in wide sizes, to contain not less than 85 % of No. 1 door cuttings, not including pieces with over two muntins, or muntins only.
		No. 3 clear factory: Lumber containing not less than 70 % of No. 1 door cuttings, not including pieces with over two muntins, or muntins only
	Shop Lower grades of factory plank yielding smaller percentages in smaller and lower-quality cuttings	No. 1 shop: Lumber of high-quality factory grade containing not less than 50 % of No. 1 door cuttings, allowing, if necessary, one No. 2 stile in any piece, but no pieces with over two muntins, or muntins only
		No. 2 shop: Lumber containing not less than 25 % No. 1 door cuttings, or 40 % No. 2 door cuttings, or $33\frac{1}{3}$ % of mixed door cuttings.
		No. 3 shop: Lumber of a shop type below the grade of No. 2 shop and better than box lumber.

Quality of Cuttings

In determining the grades of factory plank two grades of cuttings shall be recognized. These shall be known as No. 1 and No. 2 cuttings and shall conform to the following rules:

No. 1 cuttings shall be free from defects on both sides. No restrictions shall be made upon bright sapwood.

No. 2 cuttings shall admit any one of the following defects:

Light-blue stain on one side, not larger in extent than one-half the area of the side.

Medium-brown kiln or heart stain covering half the surface on one face, or a greater area of lighter stain, or a proportionate amount on two sides

A small sound and tight knot which does not exceed $\frac{5}{8}$ in. in diameter.

A small pitch pocket not over $\frac{1}{8}$ in. wide, or over 2 in. long in West Coast woods and not over $\frac{1}{8}$ in. wide or over 1 in. long in western pine and California pine.

One or more small-season checks whose combined length does not exceed 8 in.

Light pitch or small pitch streaks that do not form a pronounced defect.

Slightly torn grain on one side.

Inch Factory Lumber

It is recommended (*a*) that the grading rules for inch factory lumber, now published and applied by associations of lumber manufacturers, be adopted for tentative use; (*b*) that the subject of standard grades for inch factory lumber be given further study by the subcommittee of producers and consumers of such material and the results be reported to the Central Committee on Lumber Standards; and (*c*) that the Central Committee on Lumber Standards act upon the standard rules presented and, if found acceptable, be authorized to publish them as American Lumber Standards for inch factory lumber.

10. Strength Values of Timber.—Practically all of the working unit stresses for timber in this country are now based on tests made by the Forest Products Laboratory, Madison, Wisconsin. Values of the various working stresses are given in Appendix G.

11. Sizes and Lengths of Framing Timbers. The nominal sizes in which framing timbers may be purchased are indicated in the following table:

NOMINAL SIZES OF FRAMING TIMBER

2×4	... ...	.....	4×4								
2×6	2½×6 *	3×6	4×6	6×6							
2×8	2½×8 *	3×8	4×8	6×8	8×8						
2×10	2½×10*	3×10	4×10	6×10	8×10	10×10					
2×12	2½×12*	3×12	4×12	6×12	8×12	10×12	12×12				
2×14	2½×14*	3×14	4×14	6×14	8×14	10×14	12×14	14×14			
2×16	2½×16*	3×16	4×16	6×16	8×16	10×16	12×16	14×16	16×16		
2×18	2½×18*	3×18	4×18	6×18	8×18	10×18	12×18	14×18	16×18	18×18	
				6×20	8×20	10×20	12×20	14×20	16×20	18×20	20×20
									16×22	18×22	20×22
									16×24	18×24	20×24
										18×26	20×28
											20×30

* For yellow pine only.
All sizes above 18-in. depth for Douglas fir only.

Other sizes, such as 2 × 3, 2 × 5, 2 × 7, 2 × 9, 3 × 4, and 3 × 5 are sawed by a few mills, but are not common. 2 × 3 in Douglas Fir is shipped into California by the northern mills. The largest sizes of timbers listed in the above table are not ordinarily carried in stock, and must be ordered under special contract.

Rail shipments of dimension lumber are generally shipped surfaced one side one edge; water shipments, in the rough. If rough sizes are desired, the shipment should be so ordered under special contract.

12. Measurement of Lumber. In the United States, all lumber, except as noted below, is cut and sold in even lengths, as 12 ft., 14 ft., 16 ft., 18 ft., etc. Timbers will usually overrun such lengths a small amount. Thus a 10 × 10 timber ordered as a 16-ft. length may actually be 16 ft. 4 in. long. However, this full excess length cannot be counted upon. The excess length may be only sufficient to allow a full 16-ft. length after cutting the ends square. Any odd or fractional lengths of timbers required in a building must be purchased as the next higher even length. A study of the size of building and arrangement of walls, posts, story heights, etc. may sometimes result in a considerable saving in lumber by the elimination of cutting lengths of timbers that are slightly under standard lengths.

All lumber, except some finishing lumber, is sold by board-measure, the unit of which is the board foot. One board foot of lumber is 144 cu. in. Expressed in another way, a board foot is the equivalent of a 12-in. length of board, 1 in. thick and 12 in. wide. For example, a piece of timber 6 in. square and 14 ft. long has 42 board ft. To compute the board feet in any timber, divide the product of the sectional area of the stick and the length of the timber by the factor 12, and the result will be the number of board feet in the timber.

In making out a lumber list, the information to be given is the number of pieces, sectional dimensions, length, kind of timber, quality, and statement of whether the lumber is to be rough or surfaced.

This information is usually presented in the following manner:

4 − 8″ × 10″ − 16′ Douglas fir No. 1 common S4S.

The first number gives the number of pieces, the next two, the thickness and depth, respectively, and the fourth number the length. The smallest cross-sectional dimension is written first, thus, 2″ × 4″ rather than 4″ × 2″. The abbreviation S4S indicates that the timbers are to be surfaced four sides.

The board feet in the four sticks would be the product of the four numbers divided by 12, or 127 board ft.

Many tables are published giving the board feet measure of commercial sizes of timbers. The accompanying table shows the contents of timbers in board-measure. However, with a little practice, one can compute the quantities almost as fast as by the use of a table by performing the simpler multiplication mentally, factoring where possible. Thus, in the example given above, $80 \times 16 \times \frac{1}{3} = 80 \times 5\frac{1}{3} = 427$ board ft. The nominal cross-sectional dimensions are always used, *i.e.*, 8″ × 10″, instead of the finished dimensions, 7½″ × 9½″.

Table of Board Measure

Table shows the number of board feet in various sizes, for lengths varying from 10 to 32 ft.

Size in inches	Length in feet											
	10	12	14	16	18	20	22	24	26	28	30	32
2×4	6⅔	8	9⅓	10⅔	12	13⅓	14⅔	16	17⅓	18⅔	29	21⅓
2×6	10	12	14	16	18	20	22	24	26	28	30	32
2×8	13⅓	16	18⅔	21⅓	24	26⅔	29⅓	32	34⅔	37⅓	40	42⅔
2×10	16⅔	20	23⅓	26⅔	30	33⅓	36⅔	40	43⅓	46⅔	50	53⅓
2×12	20	24	28	32	36	40	44	48	52	56	60	64
2×14	23⅓	28	32⅔	37⅓	42	46⅔	51⅓	56	60⅔	65⅓	70	74⅔
2×16	26⅔	32	37⅓	42⅔	48	53⅓	58⅔	64	69⅓	74⅔	80	85⅓
2×18	30	36	42	48	54	60	66	72	78	84	90	96
2×20	33⅓	40	46⅔	53⅓	60	66⅔	73⅓	80	86⅔	93⅓	100	106⅔
3×6	15	18	21	24	27	30	33	36	39	42	45	48
3×8	20	24	28	32	36	40	44	48	52	56	60	64
3×10	25	30	35	40	45	50	55	60	65	70	75	80
3×12	30	36	42	48	54	60	66	72	78	84	90	96
3×14	35	42	49	56	63	70	77	84	91	98	105	112
3×16	40	48	56	64	72	80	88	96	104	112	120	128
3×18	45	54	63	72	81	90	99	108	117	126	135	144
3×20	50	60	70	80	90	100	110	120	130	140	150	160
4×4	13⅓	16	18⅔	21⅓	24	26⅔	29⅓	32	34⅔	37⅓	40	42⅔
4×6	20	24	28	32	36	50	44	48	52	56	60	64
4×8	26⅔	32	37⅓	42⅔	48	53¼	58⅔	64	69⅓	74⅔	80	85⅓
4×10	33⅓	40	46⅔	53⅓	60	66⅔	73⅓	80	86⅔	93⅓	100	106⅔
4×12	40	48	56	64	72	80	88	96	104	112	120	128
4×14	46⅔	56	65⅓	74⅔	84	93⅓	102⅔	112	121⅓	130⅔	140	149⅓
4×16	53⅓	64	74⅔	85⅓	96	106⅔	117⅓	128	138⅔	149⅓	160	170⅔
4×18	60	72	84	96	108	120	132	144	156	168	170	192
4×20	66⅔	80	93⅓	106⅔	120	133⅓	146⅔	160	173⅓	186⅔	200	213⅓
6×6	30	36	42	48	54	60	66	72	78	84	90	96
6×8	40	48	56	64	72	80	88	96	104	112	120	128
6×10	50	60	70	80	90	100	110	120	130	140	150	160
6×12	60	72	84	96	108	120	132	144	156	168	180	192
6×14	70	84	98	112	126	140	154	168	182	196	210	224
6×16	80	96	112	128	144	160	176	192	208	224	240	256
6×18	90	108	126	144	162	180	198	216	234	252	270	288
6×20	100	120	140	160	180	200	220	240	260	280	300	320
8×8	53⅓	64	74⅔	85⅓	96	106⅔	117⅓	128	138⅔	149⅓	160	170⅔
8×10	66⅔	80	93⅓	106⅔	120	133⅓	146⅔	160	173⅓	186⅔	200	213⅓
8×12	80	96	112	128	144	160	176	192	208	224	240	256
8×14	93⅓	112	130⅔	149⅓	168	186⅔	205⅓	224	242⅔	261⅓	280	298⅔
8×16	106⅔	128	149⅓	170⅔	192	213⅓	234⅔	256	277⅓	298⅔	320	341⅓
8×18	120	144	168	192	216	240	264	288	312	336	360	384
8×20	133⅓	160	186⅔	213⅓	240	266⅔	293⅓	320	346⅔	373⅓	400	426⅔
10×10	83⅓	100	116⅔	133⅓	150	166⅔	183⅓	200	216⅔	233⅓	250	266⅔
10×12	100	120	140	160	180	200	220	240	260	280	300	320
10×14	116⅔	140	163⅓	186⅔	210	233⅓	256⅔	280	303⅓	326⅔	350	373⅓
10×16	133⅓	160	186⅔	213⅓	240	266⅔	293⅓	320	346⅔	373⅓	400	426⅔
10×18	150	180	210	240	270	300	330	360	390	420	450	480
10×20	166⅔	200	233⅓	266⅔	300	333⅓	366⅔	400	433⅓	466⅔	500	533⅓
12×12	120	144	168	192	216	240	264	288	312	336	360	384
12×14	140	168	196	224	252	280	308	336	364	392	420	448
12×16	160	192	224	256	288	320	352	384	416	448	480	512
12×18	180	216	252	288	324	360	396	432	468	504	540	576
12×20	200	240	280	320	360	400	440	480	520	560	600	640

Size in inches	Length in feet											
	10	12	14	16	18	20	22	24	26	28	30	32
14×14	163⅓	196	228⅔	261⅓	294	326⅔	359⅓	392	424⅔	457⅓	490	522⅔
14×16	186⅔	224	261⅓	298⅔	336	373⅓	410⅔	448	485⅓	522⅔	560	597⅓
14×18	210	252	294	336	378	420	462	504	546	588	630	672
14×20	233⅓	280	326⅔	373⅓	420	466⅔	513⅓	560	606⅔	653⅓	700	746⅔
16×16	213⅓	256	298⅔	341⅓	384	426⅔	469⅓	512	554⅔	597⅓	640	682⅔
16×18	240	288	336	384	432	480	528	576	624	672	720	768
16×20	266⅔	320	373⅓	426⅔	480	533⅓	586⅔	640	693⅓	746⅔	800	853⅓
16×22	293⅓	352	410⅔	469⅓	528	586⅔	645⅓	704	762⅔	821⅓	880	938⅔
16×24	320	384	448	512	576	640	704	768	832	896	960	1024
18×18	270	324	378	432	486	540	594	648	702	756	810	864
18×20	300	360	420	480	540	600	660	720	780	840	900	960
18×22	330	396	462	528	594	660	726	792	858	924	990	1056
18×24	360	432	504	576	648	720	792	864	936	1008	1080	1152
20×20	333⅓	400	466⅔	533⅓	600	666⅔	733⅓	800	866⅔	933⅓	1000	1066⅔
20×22	366⅔	440	513⅓	586⅔	660	733⅓	806⅔	880	953⅓	1026⅔	1100	1173⅓
20×24	400	480	560	640	720	720	880	960	1040	1120	1200	1280
22×22	403⅓	484	564⅔	645⅓	726	806⅔	887⅓	968	1048⅔	1129⅓	1210	1290⅔
22×24	440	528	616	704	792	880	968	1056	1144	1232	1320	1408
24×24	480	576	672	768	864	960	1056	1152	1248	1344	1440	1536
26×26	563⅓	676	788⅔	901⅓	1014	1126⅔	1239⅓	1352	1464⅔	1577⅓	1690	1802⅔

Standard lengths (of lumber) are multiples of 2 ft., 4 to 24 ft., inclusive, for boards, fencing, dimension, joists and timbers; multiples of 1 ft., 4 to 20 ft., inclusive, for finishing flooring, ceiling, siding, partition, casing, base, window and door jambs—except as hereinafter specied. Longer or shorter lengths than those herein specified are special. Special fractional lengths, when ordered, will be counted as the next higher standard length.

The standard widths for lumber, S1S or S2S or rough, excluding dimension, shall be multiples of 1 in., 3 in. and up in width.

All dressed stock shall be measured and sold strip count, viz.: full size of rough material necessarily used in its manufacture. All sizes 1 in. or less in thickness shall be counted as 1 in. thick.

13. Sizes of Lumber.—The following extracts are taken from the American Lumber Standards as given in the U. S. Department of Commerce Simplified Practice Recommendation No. 16, *Lumber*, printed in 1926.

13a. Yard-lumber Size Standards.

Dressed Sizes

The terms "standard board, "extra-standard board," and "standard dimension," and "extra-standard dimension" shall be the designations for 1-in. boards (yard) and 2-in. dimension (yard), respectively, and applied to both softwoods and hardwoods.

$^{25}/_{32}$ in., S1S or S2S (measured at standard commercially dry shipping weight and moisture content for each species), shall be the thickness for the standard yard board; $^{29}/_{32}$ in., S1S or S2S, for the extra-standard yard board.

1⅝ in., S1S or S2S (measured at standard commercially dry shipping weight and moisture content for each species), shall be the thickness for standard dimension not more than 12 in. wide; 1¾ in., S1S or S2S, for extra-standard dimension.

The finished widths of finish, boards, and dimension S1E or S2E (measured at standard commercially dry shipping weight and moisture content for each species), shall be ⅜ in. off on lumber of standard widths less than 8 in. and ½ in. off on lumber of standard widths of 8 in. and over.

The thicknesses and widths of finished lumber, S1S or S2S and or S1E or S2E, shall be as follows:

FINISH, COMMON BOARDS AND STRIPS, AND DIMENSION

The thicknesses apply to all widths and the widths to all thicknesses

Product	Size, board measure		Dressed dimensions at standard commercially dry shipping weight and moisture content		
	Thickness, inches	Width, inches	Standard thickness, inches	Extra-standard thickness, inches	Standard width, inches
Finish	. .	3	5/16	.....	2 5/8
		4	7/16	.. ..	3 5/8
		5	9/16	.... .	4 5/8
		6	11/16	....	5 5/8
	1	7	25/32	26/32	6 5/8
	1 1/4	8	1 1/16	.. .	7 1/2
	1 1/2	9	1 5/16	.. ..	8 1/2
	1 3/4	10	1 7/16	.... .	9 1/2
	2	11	1 5/8	1 3/4	10 1/2
	2 1/2	12	2 1/8	. ..	11 1/2
	3	.	2 5/8		
Common boards and strips	1	3	25/32	26/32	2 5/8
	1 1/4	4	1 1/16	.. ..	3 5/8
	1 1/2	5	1 5/16	. ..	4 5/8
		6		.. .	5 5/8
		7		.....	6 5/8
		8	.	. ...	7 1/2
		9	. . .	.. ..	8 1/2
		10	....	.. ..	9 1/2
		11	....	. . .	10 1/2
		12	.. ..	.	11 1/2
Dimension	2	2	1 5/8	1 3/4	1 5/8
	2 1/2	4	2 1/8	.....	3 5/8
	3	6	2 5/8	.... .	5 5/8
	4	8	3 5/8	.... .	7 1/2
	over 4	10	Off 3/8	....	9 1/2
		12	.	..	11 1/2

Siding, Flooring, Ceiling, Partition, Ship-lap, and Dressed and Matched

The thicknesses apply to all widths and the widths to all thicknesses

Product	Size, board measure		Dressed dimensions at standard commercially dry shipping weight and moisture content	
	Thickness, inches	Width, inches	Standard thickness, inches	Standard face width, inches
Bevel siding		4	7/16* × 3/16	3 1/2
		5	10/16 × 3/16	4 1/2
		6		5 1/2
Rustic and drop siding		4	9/16	3 1/8†
		5	3/4	4 1/8†
		6		5 1/8†
		8		7 1/8†
Flooring		2	5/16	1 1/2
		3	7/16	2 3/8
		4	9/16	3 1/4
	1	5	25/32	4 1/4
	1 1/4	6	1 1/16	5 1/4
	1 1/2	.	1 5/16	
Ceiling		3	5/16	2 3/8
		4	7/16	3 1/4
		5	9/16	4 1/4
		6	11/16	5 1/4
Partition		3	3/4	2 3/8
		4		3 1/4
		5		4 1/4
		6		5 1/4
Ship-lap	1	4	25/32	3 1/8
		6		5 1/8
		8		7 1/8
		10		9 1/8
		12		11 1/8
Dressed and matched	1	4	25/32	3 1/4
	1 1/4	6	1 1/16	5 1/4
	1 1/2	8	1 5/16	7 1/4
		10		9 1/4
		12		11 1/4

* Minimum, [illegible]/16.

† Ship-lapped; face widths for D. and M. are 1/8 in. wider than for ship-lapped. In patterned material, 1 1/4 and 1 1/2 in. thick, board measure, the tongue shall be 1/4 in. wide in tongued-and-grooved lumber, and the lap 3/8 in. wide in ship-lapped lumber, with the over-all widths 1/4 in. and 3/8 in. wider, respectively, than the face widths shown above.

FACTORY FLOORING, HEAVY ROOFING, DECKING, AND SHEET PILING
The thicknesses apply to all widths and the widths to all thicknesses

Size, board measure		Dressed dimensions at standard commercially dry shipping weight and moisture content			
			Standard face width		
Thickness, inches	Width, inches	Standard thickness, inches	D. and M., inches	Ship-lapped, inches	Grooved for splines, inches
2	4	$1\frac{5}{8}$	$3\frac{1}{8}$	3	$3\frac{1}{2}$
$2\frac{1}{2}$	6	$2\frac{1}{8}$	$5\frac{1}{8}$	5	$5\frac{1}{2}$
3	8	$2\frac{5}{8}$	$7\frac{1}{8}$	7	$7\frac{1}{2}$
4	10	$3\frac{5}{8}$	$9\frac{1}{8}$	9	$9\frac{1}{2}$
	12	...	$11\frac{1}{8}$	11	$11\frac{1}{2}$

In patterned material 2 in. and thicker, the tongue shall be $\frac{3}{8}$ in. wide in tongued-and-grooved lumber, and the lap $\frac{1}{2}$ in. wide in ship-lapped lumber, with the over-all widths $\frac{3}{8}$ and $\frac{1}{2}$ in. wider, respectively, than the face widths shown above.

Rough-dry Sizes

The standard rough-dry thickness of the standard board shall be not less than $\frac{29}{32}$ in., with an allowance of 20 % of the shipment, which may be not less than $\frac{28}{32}$ in., and the standard rough-dry thickness of the extra-standard board shall be not less than $\frac{39}{32}$ in., with an allowance of 10 % of the shipment, which may be not less $\frac{29}{32}$ in.

The standard rough-dry thickness of finish, common boards, and dimension of standard sizes $1\frac{1}{4}$ in. and thicker, board measure, shall be not less than $\frac{1}{8}$ in. thicker than the corresponding standard finished dry thickness, with an allowance of 20 % of the shipment, which may be not less than $\frac{3}{32}$ in. thicker than the corresponding standard finished dry thickness.

The widths of finish, common boards, and dimension, rough and commercially dry, 7 in. and narrower, shall be not more than $\frac{1}{4}$ in. less than the nominal widths, and the widths 8 to 12 in. board measure shall be not more than $\frac{3}{8}$ in. less than the nominal widths.

Lengths

With the exception of the following enumerated odd lengths, which shall be standard, odd lengths in yard lumber and in structural material are not considered in American Lumber Standards:

2 × 4 in., 6 and 8 in. – 9 and 11 ft.
2 × 8 in. and 10 in. – 13 ft.
2 × 10 in. – 15 ft.
8 × 8 in., 10 × 10 in., 10 × 12 in., 12 × 12 in., 14 × 14 in., 16 × 16 in., 18 × 18 in. – 11 and 13 ft.
6 × 16 in., 6 × 18 in., 8 × 16 in., 8 × 18 in. – 15 and 17 ft.

Description, Measurement, and Tally

The thickness and widths of yard lumber, as specified, shall be considered *standard*. All other sizes shall be considered *special*.

Yard lumber of standard and extra-standard size shall be described by those standard dimensions.

Lumber of standard and extra-standard size shall be tallied *board measure*. On lumber of standard thickness less than 1 in. (board measure), the board-foot measurement shall be based on the surface dimensions.

The board measurement of dressed lumber of standard and extra-standard size shall be based upon the corresponding standard dimensions of rough-green lumber.

Lumber finished to special size shall be counted (tallied) as of the standard rough size necessarily used in its manufacture.

The measurement and description of the dimensions of yard lumber shall be as follows:

Thickness of yard lumber measured and described as:	Minimum thickness, S1S or S2S; at standard commercially dry shipping weight and moisture content, inches
1 in., board measure, to be not less than	$\frac{25}{32}$
$1\frac{1}{4}$ in., board measure, to be not less than	$1\frac{1}{32}$
$1\frac{1}{2}$ in., board measure, to be not less than	$1\frac{9}{32}$
$1\frac{3}{4}$ in., board measure, to be not less than	$1\frac{7}{16}$
2 in , board measure, to be not less than	$1\frac{5}{8}$
$2\frac{1}{2}$ in., board measure, to be not less than	$2\frac{1}{8}$
3 in., board measure, to be not less than	$2\frac{5}{8}$
$3\frac{1}{2}$ in., board measure, to be not less than	$3\frac{1}{8}$
4 in., board measure, to be not less than	$3\frac{5}{8}$

Widths of finish, boards, and dimension, measured and described as 2, 3, 4, 5, 6, and 7 in., board measure, to be, respectively, not less than $1\frac{5}{8}$, $2\frac{5}{8}$, $3\frac{5}{8}$, $4\frac{5}{8}$, $5\frac{5}{8}$, and $6\frac{5}{8}$ in., S1E or S2E, at standard commercially dry shipping weight and moisture content; widths of finish, boards, and dimension measured and described as 8, 9, 10, 11, and 12 in., board measure, to be, respectively, not less than $7\frac{1}{2}$, $8\frac{1}{2}$, $9\frac{1}{2}$, $10\frac{1}{2}$, and $11\frac{1}{2}$ in.

The description of thickness of dressed stock less than 1 in. thick, board measure, S1S or S2S, to be its actual thickness at standard commercially dry shipping weight and moisture content.

NOTE.—It is to be understood that the standard dimensions of rough lumber, commercially dry, are in excess of the dimensions of finished lumber of the corresponding size, board measure, by the amount necessary to permit of surfacing either one side or two sides and or one edge or two edges.

Material shipped on stock sizes shall be tallied by the number of pieces of each size and length in the shipment.

In shipments measured on board measure a piece tally in board feet shall be made.

In material measured with a board rule on actual widths, pieces measuring to the even half foot shall be alternately counted as of the next higher and lower foot count; fractions below the half foot shall be dropped, and fractions above the half foot shall be counted as of the next higher foot.

13b. Structural Lumber Sizes.—See Appendix F for detailed specifications in regard to knots, shakes and checks, angle of grain, and wane.

Douglas fir or southern pine select grade to be selected for rate of growth. Douglas fir or southern pine of dense select grade to be selected for density.

Joist and Plank

Joists, Rafters, Scaffold Plank, Factory Flooring, Etc.

Nominal thicknesses: 2 to 4 in.
Nominal widths: 4 in. and wider.
Standard thicknesses, S1S or S2S: $\frac{3}{8}$ in. off.
Extra-standard thickness, 2 in., S1S or S2S: $\frac{1}{4}$ in. off.
Standard widths, 2 to 7 in., S1E or S2E: $\frac{3}{8}$ in. off; 8 in. and wider, S1E or S2E: $\frac{1}{2}$ in. off.
Standard lengths: Multiples of 2 ft.

Beams and Stringers

Beams, Girders, Stringers, Etc.

Nominal thicknesses: 5 in. and thicker.
Nominal widths: 8 in. and wider.
Standard lengths: Multiples of 2 ft.
S1S, S1E, S2S, or S4S: $\frac{1}{2}$ in. off each way.

Posts and Timbers

Posts, Caps, Sills, Timbers, Etc.

Nominal sizes: 6 × 6 in. and larger.
Standard lengths: Multiples of 2 ft.
S1S, S1E, S2S, or S4S: $\frac{1}{2}$ in. off each way.

13c. Softwood Factory and Shop Lumber Sizes.

Dressed Thicknesses

The following thickness of factory lumber shall be considered standard. All other thicknesses shall be considered special.

Size, board measure, inches	Finished thicknesses, S1S or S2S, at commercially dry shipping weight and moisture content	
	Standard, inches	Extra standard, inches
1	25/32	29/32
1¼	1 5/32	
1½	1 13/32	
2	1 25/32	
2¼	2 1/8	
2½	2 3/8	
3	2 6/8	
4	3 5/8	

NOTE.—It is to be understood that any association which publishes and administers rules for factory lumber under the American Lumber Standards will not be required to furnish 1-in. factory lumber in both the standard and extra-standard thicknesses.

Widths

Standard widths shall be 5 in. and over; factory lumber is usually shipped in random widths, though specified widths may be shipped. Five-inch widths must be full size in the rough-dry condition.

Lengths

Standard lengths shall be 6 ft. and over in multiples of 1 ft.

Sizes of Cuttings

Stiles shall be 5 and 6 in. wide by 6 ft. 8 in. to 7 ft 6 in. long. They may be either No. 1 or No. 2 in quality.

Bottom rails shall be 9 and 10 in. wide by 2 ft. 4 in. to 3 ft. long. They may be either No. 1 or No. 2 in quality.

Muntins shall be 5 and 6 in. wide by 3 ft. 6 in. to 4 ft. long. They may be either No. 1 or No 2 in quality.

Top rails shall be 5 and 6 in. wide by 2 ft. 4 in. to 3 ft. long. They must be of No. 1 cutting quality but shall be considered as No. 2 cuttings.

Sash cuttings shall be 2½ and 3½ in. in width by 28 in. and over in length.

In computing the area of cuttings in each piece of factory plank the sizes and areas listed in the American Lumber Standards or in the U. S. Department of Commerce Simplified Practice Recommendation No. 16, *Lumber* (printed in 1926), shall be used.

14. Estimating Quantities of Sheathing, Flooring, Etc. The following rules will give quantities actually required to cover various surfaces.* The results are to be taken as approximately correct.

Sheathing.—To the actual superficial area to be covered, excluding openings, add 15% for floors, 17% for side walls, and 22½% for roofs.

If sheathing is laid diagonally, an allowance of 7% should be added to the above figures to cover waste.

The above figures are for sheathing laid tight, *i.e.*, boards not separated.

Flooring, Ceiling, and *Wainscoting.*

Square-edged: For material $3\frac{1}{2}$ in. wide, add 25%.

Dressed and Matched:

20% for 6-in. flooring
33% for 4-in. flooring
40% for 3-in. flooring

Siding.—To the net superficial area, after deducting for openings, add the following:

$33\frac{1}{3}$% for 6-in. siding laid $1\frac{1}{2}$ to $1\frac{3}{4}$ in. to the weather.
50% for 4-in. siding.

For drop siding, use the figures for flooring of the same width.

BUILDING STONES

By H. Ries

Under this heading are included all natural rocks employed for ordinary masonry work, including interior and exterior decoration, roofing, and flagging. At the present day several kinds of artificial stone are made and some of these, such as artificial marble, may be good imitations, but they are rarely adapted for exterior work.

Most of the building stone quarried is for ordinary dimension blocks, which may be sold in the rough and dressed later. With stone for ornamental purposes must be considered: (1) the possibility of carving, sometimes to intricate and beautiful designs for buildings and monuments; (2) the ability to take a high and durable polish, often called for in marbles and granites; and (3) fine and uniform texture, as well as contrast between chiseled and polished surfaces, both necessary in stone for inscriptional purposes.

The factors which affect the selection of a building stone may be cost, strength, durability, and ornamental value.

15. Minerals in Building Stones.—Only a small number of mineral species are important constituents of building stones. A few are present in very small amounts, as scattered grains, sometimes of microscopic size. These in many cases have little or no effect on the quality of the stone. The more important ones are as follows:

Quartz.—Quartz, or silica, is very abundant in some building stones, such as sandstones, granites, and some gneisses. Flint and chert are amorphous or non-crystalline forms of silica, often of dark color, and occurring as concretionary masses in certain rocks, especially limestones. In these it often stands out in the weathered surface as knots, and its presence is undesirable.

Feldspar. *Orthoclase*, the potash feldspar, is a silicate of alumina and potash. It is a common constituent of granites and many gneisses, and is also present in the variety of sandstone known as arkose. It shows two sets of cleavage planes which intersect at right angles. *Plagioclase* feldspar, commonly referred to as the lime soda feldspar, is a common constituent of some basic igneous rocks in which quartz is rare or absent.

Micas.—Micas are platy minerals, all silicates, of complex and somewhat variable composition. They have a perfect cleavage, and hence split readily into thin elastic leaves.

Amphibole. Amphibole, a complex silicate, has two varieties which are most likely to occur in building stones; these are hornblende and tremolite. *Hornblende* is dark green, brown, or black in color, and usually occurs in compact, sometimes bladed crystals of fair lustre. It is an important constituent of many igneous rocks, and of some metamorphic gneisses and schists. *Tremolite*, a pale green variety, occurs in some marbles, forming usually bladelike or silky-looking masses. It is an injurious mineral, as it decomposes readily. Its occurrence in the quarry is apt to be very irregular.

Pyroxene.—Pyroxene has a composition and color similar to amphibole, and often is not distinguishable from hornblende with the naked eye. One dark colored variety, *augite*, is an essential constituent of some igenous rocks. It takes a good polish and has fair durability.

Calcite.—Calcite, the carbonate of lime, is white when pure, effervesces readily with hydrochloric acid, and has good rhombohedral cleavage. It is an important, and sometimes the only constituent of limestone, marble, and onyx. It may occur in the cementing material of sandstone and shale. If present in igneous rocks, it is a secondary and not an original constituent. Calcite is slightly soluble in surface water containing a little acid which results in some limestones and marbles showing solution cavities of variable size.

Dolomite.—Dolomite, the double carbonate of lime and magnesia, resembles calcite, but is slightly harder and effervesces only with warm acid. It is a common constituent of many limestones and marbles.

Gypsum.—Gypsum, the hydrous sulphate of ime, is the chief constituent of those stratified rocks known as rock gypsum, and is not found in many building stones. It is soft enough to be scratched with the thumbnail. Alabaster, the fine grained, white massive variety, is translucent in thin plates and has been used for ornamental purposes.

Serpentine.—Serpentine, a hydrous silicate of magnesia, is a green or yellow material of soapy feel, no cleavage, and soft enough to be easily scratched with a knife. In massive form it is a common and important constituent of the serpentine or verd antique marbles, but occurs sometimes as specks or lumps in ordinary marble. Its resistance to weather is low.

Pyrite.—Pyrite, or iron pyrite, the iron disulphide, may occur in all kinds of rocks. Its yellow color and metallic lustre make it easily recognizable. It is an undesirable constituent of building stones since it weathers easily to limonite, producing a rusty stain.

Limonite.—Limonite, a hydrous iron oxide, is common in the cementing material of some sedimentary rocks, especially sandstones, but in others may be formed by the weathering of iron-bearing silicates.

16. Rocks Used for Building Stones.—A rock may be defined as an aggregation of minerals forming a portion of the earth's crust. Rocks can be divided into the three following groups: igneous rocks, stratified rocks, and metamorphic rocks.

16a. Igneous Rocks.—Igneous rocks are formed by the cooling of a molten mass. With few exceptions they agree in being of massive structure, more or less crystalline texture, and free from statification planes. The following are the characters of the common types:

Granites.—Composed essentially of quartz and orthoclase feldspar, but usually containing some mica, amphibole, or pyroxene. *Texture*—coarse to fine, usually even, sometimes porphyritic. *Color*—variable, pink, gray, or white common. Valuable as a building stone because of usually high durability, variety of color and texture, and susceptibility of taking a high polish. The darker granites often give excellent contrast between hammered and polished surface.

Pegmatite.—Usually of very coarse grain, occurring commonly in the form of dikes. It is of no value as a building stone and its occurrence in some granite quarries causes serious waste.

Syenite.—An even granular rock, resembling granite in texture, composed chiefly of orthoclase feldspar, but usually having some hornblende, mica, or pyroxene. *Color*—usually white, pink, or gray. Takes a good polish but of little importance as a building stone because of its restricted occurrence.

Diorite.—Similar to granite in texture, composed of hornblende and plagioclase feldspar, often much biotite. *Color*—dark gray or greenish. Not as common as granite. Takes good polish and sometimes of very ornamental character.

Gabbro.—Like granite in texture. Consists chiefly of pyroxene and plagioclase feldspar; the former sometimes predominating to such an extent as to give the stone a very dark color. *Color*—dark gray or greenish to black. A common rock in the United States, being known in New England, the Adirondacks, Maryland, Minnesota, Rocky Mountains, and California.

Diabase or *Trap.*—Dark, fine grained, containing plagioclase and pyroxene as essential constituents. Differs from gabbro in manner of distribution of minerals, which gives it characteristic appearance. Sometimes almost black on rock face and polished surfaces. Very hard.

Basalt.—Agrees with gabbro mineralogically, but is finer grained, gray to black, and sometimes cellular. Occurs as lava flows. Not important. Much jointed.

16b. Stratified Rocks.—Stratified rocks are derived from the weathering products of pre-existing rocks and laid down by water or sometimes by wind. They show a stratified or layered structure with texture varying from coarse to fine. The hardness is due to cement (usually iron oxide, silica, or lime carbonate) deposited between the grains, and hence the degree of hardness depends on amount of cementing material. Beds are of variable thickness, hence only the thick bedded ones are of value for dimension stone. Thin bedded ones may be useful for flagging or curbing. Important types are:

Sandstone.—Grains are chiefly quartz of varying size and regularity, bound together by some kind of mineral cement. Color is variable. Varieties are *micaceous* sandstone, with abundant mica scales; *argillaceous* sandstone, containing considerable clay; and *arkose*, containing angular feldspar fragments, usually in abundance.

Conglomerate.—Stratified rock composed of pebbles of rounded character and more or less cemented together. Pebbles may be of different kinds of rocks but quartz ones are common. Conglomerates may grade into sandstones. Not much used for building stone.

Shale.—A thin layered clay rock, formed by consolidation of clay. No value as a building stone. Sometimes of value for making brick, tile, and other burned clay products.

Limestone.—As used in its broadest sense, the term includes rocks which are made up largely of calcite or dolomite, or both. Properly speaking, limestone is applied to the calcite rocks, and dolomite to the dolomitic ones. There is no sharp line of separation between the two. Colors of limestone and dolomite are variable, but white, gray, or black are common; hardness is also variable. Sand and clay are sometimes common impurities. *Texture*—

coarse to fine. Some varieties contain large quantities of shells and other fossils. Flint and pyrite may be present in some.

Varieties of limestone proper are: *chalk*, a soft limestone, of earthy texture and usually white color; *travertine*, a lime carbonate deposit from springs; *coquina*, a loosely cemented shell aggregate; and *onyx*, a dense crystalline form of lime carbonate, deposited usually on the floor of caves by percolating water carrying lime carbonate.

16c. Metamorphic Rocks.—Metamorphic rocks are those formed by a reorganization of preexisting rocks, through the action of pressure, heat, and water. They usually show a crystalline or grained texture, foliated or banded structure, and low porosity. Important types are:

Quartzite.—Hard siliceous rock differing from sandstone in being denser and harder.

Slate.—A clay rock, harder than shale, and possessing a well developed cleavage. *Color*—gray, black, green, red, and purple. *Texture*—very fine.

Marble.—A crystalline limestone or dolomite. Texture and color, variable. May contain silicate minerals, graphite, or other mineral matter scattered through it in grains, streaks, or blotches. Pure marble is white.

Gneiss.—A banded metamorphic rock often having the same mineral composition as granite or sometimes of other igneous rocks. Color is variable.

Schist.—More thinly foliated than gneiss, due usually to an excess of bladed or scaly minerals, such as mica. Is of little value as a building stone.

17. Properties and Testing of Building Stones.—The properties of a stone exert a distinct influence on its uses and durability. There are standarized tests for some.

Texture.—The texture, or the grain of the stone, varies from coarse to fine, or regular to irregular. Uniformity of grain is desirable.

The grains of sandstone are usually rounded but may be angular. The grains of igneous and metamorphic rocks are angular. Limestones are usually fine grained, but may be very coarse if made up largely of shells, or have an oolitic structure. Marbles are apt to show uniform texture though some may have the grains more elongated in one direction than another. Greater elongation in one direction affects the splitting qualities of the stone and should not be overlooked. Texture of marble is affected by mineral impurities and folding. White Alabama marble and Italian Carrara are fine grained, while Georgia marble is coarse grained. Granites show a wide range of texture but do not reach as great a degree of fineness as marbles.

Dale has graded Vermont marbles as follows:

GRAIN DIAMETER

	Maximum average		General average	
	Millimeters	Millimeters	Millimeters	Inches
1. Extra fine	0.2	0.05-0.10	0.06	0.0023
2. Very fine	0.5	0.07-0.16	0.10	0.0039
3. Fine	0.75	0.10-0.25	0.12	0.0047
4. Medium	1.00	0.12-0.31	0.15	0.0059
5. Coarse	1.50	0.20-0.60	0.24	0.0094
6. Extra coarse	2.54	0.30-1.35	0.50	0.0196

Hardness.—The hardness of a rock depends on the state of aggregation of its component mineral grains. A sandstone may be made up entirely of hard quartz grains very loosely cemented, so that the rock is soft. There is no standard test for hardness of stone. It can be tested by measuring its abrasive resistance, or the rate of penetration of a drill.

Color.—Building stones show a variety of colors including white, brown, red, yellow, gray, buff, black, etc. These are sometimes a blend of the colors of the component minerals.

Sandstones owe their color to the character of the cementing material. Limestones, if pure, are white; but carbonaceous matter frequently colors them gray or black. Pure marbles are white. Graphitic material colors them gray or black, while silicate mineral impurities give

them various colors, the latter often being disposed in bands or cloudings. In igneous rocks and gneisses, the color is commonly due to that of the prevailing minerals, as the pink color of orthoclase in many granites. Change of color is common in some rocks but it does not necessarily indicate decay of the stone. Green slates especially may fade; dark limestones may become lighter colored on the surface; some pink granites also fade; sandstones occasionally develop a rusty hue, the *Berea grit* of Ohio being a well-known case. Some bluish limestones may turn buff on exposure due to the change of the iron in them from the carbonate to the oxide. Atmospheric dust may speedily discolor light stones, such as white marble. A white scum seen on the surface of sandstones is an efflorescence derived from soluble salts. These may come from the stone itself or from the mortar.

Permanence of color can often be gaged by comparison of a fresh surface with a weathered one.

Lighter colored stones are more in demand for general work than dark colored ones, and an otherwise perfectly good stone is sometimes rejected because its color is undesirable.

Polish.—This is affected by the density and character of mineral constituents. Dense stones take a better polish than porous ones. An aggregation of different minerals gives a less continuous polish than a mass of the same minerals. Quartz, feldspar, calcite, and dolomite polish well, hornblende and augite less so, while mica is difficult to polish.

Porosity.—The percentage of pore space varies with different rocks. Granitic rocks, marbles, gneisses, quartzites, and most limestones have low porosity. Sandstone is usually fairly porous; volcanic tuffs, some lavas, and soft limestones may show high porosity.

Porosity may be determined by the following formula:

$$P = \frac{W - D}{W - S}(100)$$

in which P = per cent. porosity, W = saturated weight, D = dry weight, and S = suspended weight of saturated stone. Saturation may be obtained by soaking the stone in water for 24 hr. and then boiling for at least 1 hr.

A fact often overlooked is that the pores of a stone may vary in size and shape. Straight open pores permit ready drainage of absorbed water. Narrow tortuous pores impede it. Two stones of equal porosity might therefore retain absorbed water quite differently because of difference in size and shape of pores.

Stones of high porosity usually show high absorption, but not necessarily low frost resistance. Some of high porosity may show low absorption because of low permeability, the latter being influenced by ease with which the water can pass from one pore to another.

The following figures give the range of porosity for several kinds of building stones from different regions.

	Wisconsin	Missouri	Ontario
Granites	0.19–0.62	0.255–1.152	0.066–15.88
Limestones	0.55–13.36	0.32–13.38	4.917–17.517
Sandstones	4.81–28.28	7.01 –23.77	0.201– 0.628

Absorption.—This refers to the amount of water that a stone will absorb when immersed under atmospheric pressure and should not be confused with porosity. While stones of low porosity can absorb little water and others with high porosity may absorb much water, the aborption does not stand in a constant direct relation to the porosity. Moreover, the water absorbed by cold immersion under atmospheric pressure does not usually completely fill the pores.

Dense rocks like granites, gneisses, slates, marbles, quartzites, and many limestones, usually show a low absorption, often under 1 %. Others including many sandstones, some mestones, and many lava or tuff rocks may absorb from 2 % up to perhaps 15 % of water.

To test the absorption, a piece of the stone is thoroughly dried at 110 deg. C., weighed, and then immersed in water for 48 hr., after which it is weighed again. The increase in weight represents the weight of water absorbed, and the percentage of absorption is calculated in terms of the original dry weight. Immersing the stone under a vacuum is sometimes advocated, but this gives misleading results as it causes the stone to absorb more water than it normally would.

The quantity absorbed under different conditions does not always show great variation in dense rocks, but may vary considerably in porous ones.

The following tests by Parks give the average ratios of absorption for different rocks under different conditions.

Kind	One hour immersion	Two hours immersion	Slow immersion	Vacuum immersion	Immersion under pressure
Average of 10 sandstones	2.411	2.665	3.552	4.090	4.518
Average of 16 granites	0.232	0.243	0.298	0.371	0.401
Average of 10 marbles	0.095	0.103	0.117	0.134	0.147

As a building stone in use absorbs water under atmospheric pressure, and usually only from one side, even the ordinary form of testing is liable to make the stone absorb more water than it would in use.

Permeability.—Water will permeate stone even though of low porosity, resulting sometimes in discoloration by the liquid carrying coloring materials. It has been found that the permeability does not stand in any direct relation to the porosity, as shown by the following table:

Stone	Porosity per cent.	Permeability C.c. of water passing through 3 mm. plate in 1 hr. under 15-lb. pressure per sq. in.
Guelph limestone	15.883	90.5
Guelph limestone	11.62	155.1
Chazy sandstone	17.517	2.25
Medina sandstone	10.41	2130.00
Niagara limestone	10.443	12.75
Beekmantown limestone	1.313	0.72
Potsdam limestone	4.917	1.75

In every case the permeability gradually decreased

Stone may be tested for permeability by cutting slices of the stone 3 mm. thick in a direction at right angles to the bedding. Water is then forced through these under a pressure of 15 lb. per sq. in., and the amount of flow in 1 hr. recorded.

Quarry Water.—Rocks in the ground contain more or less water in their pores. Quarrymen call this quarry water and it is necessary on removal of stone from quarry to let this water dry out, or allow the stone to "season." Drying out of the quarry water, especially that from the smallest pores, is accompanied by the deposition of the dissolved mineral matter which it contains. This makes the rock often appreciably harder. Its effect is most pronounced in the case of porous sandstones and limestones.

A stone should not be allowed to freeze during seasoning as the quarry water freezing within its pores may cause it to split. Slate must be split before the quarry water dries out, and many stones carve much easier before seasoning, which in some cases makes the stone appreciably harder.

The working faces in some quarries are sometimes protected during the freezing season either by covering the face, or filling the quarry with water.

Since quarry water travels more readily along the rift or bedding, placing a block on edge with one side in sand, often prevents disintegration by freezing.

Strength.—The strength of a stone is governed: (1) by the rock structure, such as rift, cleavage, and bedding; (2) by the hardness of the grains; and (3) by the state of aggregations, as whether interlocked or cemented, and in the latter case by the nature of the cement.

Many tests have shown that most building stones have 2 to 10 times the crushing strength required in any structure where they will be used.

The minimum strength permissible can be determined only by a trained engineer or architect, and while few cases of yielding due to crushing are observed, failures due to stresses applied in other ways are not uncommon.

Crushing Strength.—Buckley states that the stone at the base of the Washington monument sustains a pressure of 314.6 lb. per sq. in., and that, in the tallest buildings the maximum pressure at the base is not more than half of this. Assuming, as a wide factor of safety, that a stone should have 20 times this strength, a resistance of 3146 lb. per sq. in. will answer all ordinary requirements.

Almost any reputable stone may be used in the construction of ordinary walls, but all may not be suitable for special architectural elements, as pillars, or railroad piers which may not only have to sustain a very great weight, but also be subject to jars.

Stones of high crushing strength are in general denser and heavier than those of low crushing strength, and hence more durable, but there are not a few exceptions to the last.

Most building stones show a loss in crushing strength after freezing. Tests for crushing stones are made upon cubes of the stone, preferably of 2-in. size.

The following table gives the crushing strength of a number of different kinds:

Kind	Locality	Crushing strength, lb. per sq. in.	
		Fresh	Frozen
Granite	Athelstone, Wis.	19,988	10,619
Granite	Montello, Wis.	38,244	35,045
Granite	Brockville, Ont.	26,209	24,634
Gneiss	Hall, Ont.	33,453	32,271
Limestone	Duck Creek, Wis.	24,522	28,392
Limestone	Sturgeon Bay, Wis.	35,970	20,777
Limestone	Thebault, Ont.	17,604	17,600
Sandstone	Presque Isle, Wis.	5,195	5,930
Sandstone	North Carolina	10,322	6,625
Sandstone	Perth, Ont.	31,793	28,912
Sandstone	Pembroke, Ont.	9,539	10,673

Following is the range showing by several classes of stones:

State	Kind	Range, lb. per sq. in.
Missouri	Limestone	5,714—27,183 on bed
Missouri	Limestone	5,774—25,577 on edge
Missouri	Sandstone	4,371—9,002 on bed
Missouri	Sandstone	3,933— 9,200 on edge
Missouri	Granite	18,236—19,410
Wisconsin	Igneous rocks	15,009—47,674
Wisconsin	Limestone	6,675—42,787 on bed
Wisconsin	Limestone	7,508—50,453 on edge
Wisconsin	Sandstone	4,340—13,669 on bed
Wisconsin	Sandstone	1,763—12,566 on edge
Iowa	Limestone	2,470—16,435
Iowa	Sandstone	3,600—13,900

For working compressive strength of stone masonry, see Appendix *I*.

Transverse Strength.—The transverse strength is not necessarily related to the crushing strength. Following are the ranges shown by several classes of stone:

Kind	Modulus of rupture		
	Wisconsin	Missouri	Ontario
Granite	2324.3–3909.7	....	1546–3382
Limestone	1164.3–4659.2	851.30–3311.6	817–4291
Sandstone	362.9–1321.0	418.61–1321.76	417–2186
	....	....	1891–3734

Elasticity.—Buckley gives the following figures showing modulus of elasticity in Wisconsin stones:

	Average	Minimum	Maximum
Granites and rhyolities	1,111,000	156,000	2,070,000
Limestones	786,000	31,500	1,835,700
Sandstones	165,000	32,000	400,800

Shearing Strength—Shearing is a form of stress likely to be brought to bear on stone in some parts of buildings. Three granites tested showed a shearing strength of from 1742 to 2872 lb. per sq. in.; three sandstones ranged from 992 to 1383; and two marbles gave 1163 to 1554.

Frost Resistance.—Alternate heating and cooling of a stone causes expansion and contraction, which may be detrimental to it, but if the stone is dry the injury is insignificant. With water present in the pores, the effects may be quite different. When water freezes it expands, and if this water is imprisoned in the pores of the stone, it may exert sufficient internal pressure to split it, and so since the amount of water which may be present in a stone is related to the pore space, its resistance to frost is closely connected with that of porosity.

The frost resistance of a stone depends on: (1) whether or not the pores are full of water at the time freezing occurs; (2) the shape and size of the pores, large and straight pores either allowing the water to drain off rapidly before it does any damage, or else permitting the ice to force its way outward thus relieving internal pressure; and (3) the amount of pore space, for the higher the percentage, provided the pores are of equal size and the degree of saturation equal, the greater the damage from freezing.

Pores may be of two kinds, capillary and sub-capillary, the latter remaining filled under ordinary draining. Under normal conditions, only a small proportion of the sub-capillary pores become filled with water and the worst possible condition would be represented by the complete filling of these. So a stone with a large proportion of fine pores is more liable to be injured by freezing. Therefore, the ratio between fine pore space and total pore space, gives a factor in judging the ability of a stone to withstand frost. Hirschwald obtains this factor as follows:

A dried and weighed test-cube is immersed in water for from 1 to 2 hr. if the stone is to be used above ground, and for from 2 to 30 days if the stone is to be used below the ground. The increased weight of cube represents the fine pore space that would be filled under worst possible natural conditions. Next the cube is completely saturated by immersion under vacuum or strong atmospheric pressure, and weighed again. The quotient obtained by dividing the increase representing the fine pores by the increase representing the total pores gives the proportion of fine pore space to total pore space and is termed the *saturation coefficient*. If the quotient is greater than 0.9, there is danger of the stone being injured by frost, but if less than 0.9 no injury can result.

Parks in carrying out the above tests on a series of Ontario stones for work above ground, found that the saturation coefficient for granites and gneisses ranged from 0.67 to 0.8; seven marbles ranged from 0.44 to 0.94, the finer grained types giving higher results than coarse grained ones; sandstones ranged from 0.21 to 0.57, while the limestones varied from 0.11 to 0.91.

The usual but unsatisfactory method of testing frost resistance consists in thoroughly drying a cube of stone and then weighing, after which it is soaked in water for 36 hr. It is then subjected to 40 alternate freezings and thawings. Following this the stone is dried and reweighed. Loss in weight indicates particles chipped off by freezing.

Fire Resistance.—Building stones often suffer serious injury when exposed to fire, or the combined effects of fire and water. Stone expands when heated and contracts when cooled, but the amount for a bar 1 ft. long, heated 1 deg., is exceedingly small, granite for example expanding 0.000004825 in. per ft. for each degree. When subjected to fire, a stone is rapidly heated and expanded, and if doused with water undergoes equally rapid cooling and contraction. Moreover, stones are poor conductors of heat, hence the exterior of a large block may be quite hot, while the interior is still cool, thus setting up stresses which disrupt the stone. Few stones have good fire resistance as witnessed by their spalling off during conflagrations. However, some stand up better than others. Rocks of close fabric, interlocked grains, and simple mineral composition seem to show the best resistance. Tests by McCourt indicated that most stones were fairly resistant up to 550 deg. C. At 850 deg. C. all were more or less injured; granites and gneisses spalled and cracked; sandstones parted along the bedding planes, a few developing cross fractures; limestones were little injured up to temperature of calcination but after that failed badly; marbles developed cracks before the calcination temperature was reached.

In testing for fire resistance, a cube of stone of not less than 3 or 4-in. size is employed, smaller sizes giving unreliable results as the stone gets heated through too readily. Pairs of cubes are heated to 550 and 850 deg. C., respectively, one of each pair being allowed to cool slowly, the other cooled rapidly by being plunged into cold water. A fifth cube is exposed to a large flame blast for 5 min., allowed to cool in air for 1 min., and again blasted, this alternation being repeated until the stone cracks. A sixth cube is alternately exposed to the action of the blast and a stream of cold water. All damage to the cubes is noted.

Abrasive Resistance.—This property depends on the state of aggregation of the mineral particles and in part on their individual hardness. Different stones wear very differently, and one of uneven hardness may wear in very irregular manner. The use of stones in steps or even floors of public buildings where there is much passing, serves well to bring out their resistance to abrasion.

Abrasion may also be caused by wind blown sand and dust and the effects of this will sometimes smooth or polish rocks as hard as quartzite.

It is not uncommon to find uneven marble floors due to the fact that tiles of uneven hardness set side by side have worn down very unevenly.

A common method of testing abrasive resistance consists in laying a slab of this stone to be tested on a grinding table, weighting it down, and applying emery or some other abrasive at a given rate while the table revolves a certain number of times. The stone is weighed before and after the test and the loss in weight noted. An objection to this method is the difficulty of feeding the abrasive uniformly under the test piece.

A second suggested method consists in forcing sand through a 6-cm. opening under a dry steam pressure of 3 atmospheres for 2 min. The stone to be tested is held immediately over the opening. This test is supposed to determine not only the extent to which the stone will be abraded under the given conditions, but also brings out irregularities in hardness.

Specific Gravity and Weight per Cubic Foot.—The apparent specific gravity of a rock may differ from the specific gravity of its component minerals, the former being influenced by the porosity. A rock of high porosity will have a low apparent specific gravity.

Bowles gives the following figures illustrative of the above:—Friable sandstone: specific gravity, 1.825; weight per cubic foot, 113.1 lb.; ratio of absorption, 1.8. Quartzite: specific gravity, 2.729; weight per cubic foot, 170.6 lb.; ratio of absorption, 1.566.

Softening Effect of Water.—The cementing material of some stones, such as sedimentary ones, may be softened by contact with water. The degree to which the stone is affected is

taken as an index of its durability. By determining the tensile strength of a dry piece and one that has been soaked for 28 days, and dividing the latter by the former we obtain the softening coefficient.

Corrosion by Gases.—Both oxygen and carbon dioxide when brought in contact with stone through the medium of moisture, may cause corrosion. Oxygen will cause the change of pyrite to limonite, or the rusting of other iron minerals. Carbon dioxide causes slow superficial disintegration at least by solution of carbonate compounds. Sulphurous fumes may be more injurious than those of carbon dioxide. Tests along these lines, carried on for several weeks or months, give measurable results.

The test for corrosion may be carried out as follows: Cubes of approximately 1-in. size may be used, dried at 110 deg. C., carefully weighed, and the exact superficial area determined. They are then suspended by threads in a bottle of distilled water into which a stream of carbonic acid gas is conducted. The water is renewed every few days and the treatment continued for 4 weeks. At the end of this time the specimens are removed, washed in distilled water, carefully rubbed with the finger tips to remove loose particles, thoroughly dried, and weighed. The loss in weight denotes amount of damage caused by the carbonic acid gas and may be expressed in grains per square inch of surface exposed.

Microscopic Examination of Stone.—Microscopic examination as an aid to the study of building stone, has received considerable emphasis in recent years. Such an examination should be made by one familiar with the subject and may give valuable information regarding structural defects likely to cause trouble, the cause of differences in workability of two stones, the presence of injurious minerals not easily seen with the naked eye, etc.

Sonorousness.—This test is specially applied to marbles and slates. When a good slate or sound dense piece of marble in form of a slab is suspended, it gives a clear sound when struck with a hard object. Mica slates are usually more sonorous than clay slates. Solid massive marbles are more sonorous than brecciated ones.

Special Tests for Slate.—All of the tests previously referred to may be applied to slate, but certain ones may be applied because of certain special uses to which it is put. These are as follows:

Cleavability.—This is to determine the ease and smoothness with which the slate cleaves. It should be determined by a good workman using a thin chisel with a 2-in. edge.

Character of Cleavage Surface.—In general, the smoother the surface the better, as it gives less chance for lodgment of injurious materials. Its smoothness may be examined with a hand lens. A good slate also, when scaled along cleavage, should show thin chips with translucent edges. Most good slates show little or no observable texture to the naked eye.

Presence of Lime Carbonate.—This is determined roughly by treating the slate with dilute hydrochloric acid. A slate with high lime carbonate content is generally less durable.

Presence of Magnetite.—To roughly determine this an inch cube may be pulverized, and tested with a magnet. For electrical purposes slate with magnetite is undesirable.

Toughness or Elasticity.—This is tested by measuring the deflection when a slate is placed on supports 22 in. apart, and pressure applied from above.

Corrodibility.—The resistance to corrosion is determined by immersing a weighed piece of slate in a solution consisting of 98 parts water, 1 part sulphuric acid, and 1 part hydrochloric acid. After soaking 40 hr., the stone is dried and weighed, the loss in weight being noted.

Special Tests for Marble.—In addition to the usual tests that may be applied to all building stones, the following are specially used for marbles:

Porosity.—A sawed block 2 × 1 × 1 in. is thoroughly dried out and then immersed for 48 hr. in a concentrated 4% alcoholic solution of nigrosine, a deep blue dye soluble in alcohol. After drying for half an hour the blocks are split with hammer and chisel, and the degree of porosity is indicated by the extent to which the color has penetrated the blocks.

This test is important because of the frequent combination of metals and marbles on exposed faces. The oxidation of the metal yields coloring compounds which may be absorbed by the marble.

Translucence.—The marble is cut into thin slabs and the degree to which it transmits light may be determined by ordinary photometric methods. Marbles show great differences in their light transmitting capacity, and this effects their translucence. Few marbles have been tested in this manner. The best Pentellic marble allowed light to penetrate 0.59 in., Parian marble, 1.37 in., Carrara statuary marble, 1.18 to 1.57 in.

Statuary Test.—Marble for statuary purposes should be inspected on a dull day with a good light, the surface examined being wet. It should show uniform texture, fine grain, and freedom from veins and discoloration.

Durability of Stone.—This is a question of great practical importance. No stones are of eternal lasting power but some withstand the weathering agents for several centuries while others show signs of decay in a few years or even in a few months. The factors governing durability are: (1) physical and mineralogical characters of the stone; (2) climatic conditions; and (3) location in building. Much valuable information can be obtained by observing stones in buildings long exposed to weather or the weathered surface in quarries.

Julien, as a result of observation on buildings in New York City, gives the life of different stones in that climate as follows:

Kind	Life in years, or length of time before repairs are necessary
Coarse brownstone	5 to 15
Fine laminated brownstone	20 to 50
Compact brownstone	100 to 200
Nova Scotia sandstone, untried	50 to 200 perhaps
Ohio sandstone (best siliceous variety) perhaps from one to many centuries	
Coarse fossiliferous limestone	20 to 40
Fine oölitic (French) limestone	30 to 40
Marble, coarse dolomitic	40
Marble, fine dolomitic	60 to 80
Marble, fine	50 to 100
Granite	75 to 200
Gneiss, 50 yr. to many centuries.	

A stone for interior work does not require the weather resistance of one for outside work. Stone for exterior use meets different conditions whether used above or below ground, or even whether exposed in a vertical surface where water drains off rapidly, or in a horizontal surface where it can accumulate.

The changes produced in a building stone are those incident to ordinary weathering and may be of either physical or chemical nature. Among these, frost action is as a rule the most destructive, searching out the most minute cracks and causing the chipping or flaking off of pieces of rock. The Connecticut brownstone so extensively used in former years in the eastern cities and usually set in the building on edge, often shows serious injury from frost. Warmth and humidity are also potent agents of weathering.

Certain structural irregularities, like grains or lumps of pyrite, veins of calcite, fossil shells, and even chert nodules may hasten the decay of a stone.

In the quarry the rock adjacent to weathered joints is often sufficiently altered to require rejection.

Acid gases in the atmosphere, coming in contact with limestones or marbles, or sandstones containing calcareous cement, also work for the slow destruction of the stone. In the latter case, sulphuric acid gases attacking carbonates may form soluble sulphates, which are brought to the surface as the wet stone dries out. There they may form a white scum on the surface or if the salts crystallize in the pores of the stone just below the surface, a scaling off of the stone is likely to follow.

18. Styles of Dressing Stone.—*Rubble* is stone of all shapes and sizes that is laid up with little or no regularity. Walls laid up this way are known as rubble work. *Coursing* stone is a term applied when the wall is laid up in tiers or courses. The stones may or may not be cut to equal length to resemble brick work. *Random coursing* refers to walls built up of rectangular and bedded blocks of various sizes. *Dimension stone* properly applies to stone cut to size.

The recognized methods of surfacing are: (1) *rock face*—natural broken surface of the stone; (2) *pointed face*—surface dressed comparatively flat by means of the point; (3) *hammered face*—surface made plane by hammering with patent hammers of different kinds; (4) *ribbed* or *tooth chiseled*—surface obtained by using a wide flat-toothed chisel, or more often produced by machinery, a common type of finish for many soft stones; (5) *sand finished*—produced by rubbing a surface smooth with sand, often applied to marble for exterior work.

19. Dressing Machines—*Gang Saw.*—Used for cutting large blocks up into slabs. Consists of an upright rectangular frame with a large post of wood or steel at each corner. Suspended

from this and free to swing between the posts, is a horizontal steel sash which can be raised or lowered. The sash is given a sawing motion by means of a pitman, which in turn is operated by a belt-driven crank attached to a fly wheel. The saws, which are bands of soft steel 3 in. wide and ⅜ in. thick, are stretched between the head pieces of the sash, and held in position by keys. The spacing of the saws determines the thickness of the slabs cut. During operation a continuous supply of sand and water is fed over the stone and it is the sharp sand which cuts the stone. The overflow is caught in a hopper below the block, and used over again. The above type is generally used for marble and limestone. For granite and hard sandstone a modified form of structure is used, the saw blades are heavier and notched on the edge, and chilled shot or crushed steel is the abrasive.

At one Vermont marble mill the standard saws will cut a block 10 ft. long, 6 ft. wide, and 6 ft. high. At another mill, saws working on blocks of marble 6 ft. long, sink 1 in. per hour.

Rubbing Bed.—This consists essentially of a revolving steel plate or table from 4 to 14 ft. in diameter, and driven at a rate of 44 to 48 revolutions per minute. A wooden box surrounding the plate prevents scattering of sand and water. The stone is placed face down on the rubbing bed and weighted. A cross bar above the table also holds it stationery. Sand and water are supplied during the operation.

Planing Machines.—In these the stone is moved to and fro on a horizontal bed, while it is subjected to the cutting of grooves, channels, or cornices.

Lathes.—These are used for turning columns or other round work. The cutting is usually done with a fixed chisel, but in granite work, the chisel is replaced by a steel disc set obliquely against the stone and rotating with it.

Gritting and Polishing Machines.—These give the stone further treatment after the rubbing bed. The machines vary in weight and rigidity according to class of work. Marble gritters and polishers differ in character of abrasive and speed of rotation. With granite, the head or polishing surface is quite different from that used for marble.

The machine consists of a horizontally rotating disc to which different types of head can be attached. The upright spindle and disc are rotated at the end of a jointed adjustable arm so that the polishing surface may be moved over all parts of the stone. For marble gritting the heads are 12 in. diameter, with blocks of abrasives attached in a radial manner on the under side. Finer grades are used as polishing proceeds. Scotch hone is used for final operation, operating at 200 r.p.m. Polishers or buffers have felt heads about 20 in. in diameter, operating at 400 r.p.m. Putty powder produces the gloss.

Diamond Saw.—This is used for making single cuts. There are several types but all consist essentially of a steel disc in the margin of which a number of carbons are mounted.

Carborundum Machines.—Carborundum wheels are extensively used in marble finishing shops for curved work, moldings, cornices, balusters, etc. The carborundum wheel is first set in a lathe, and with a steel tool cut to shape of negative of pattern desired. The wheel is then placed on a shaft and marble block on the machine bed travels beneath it. Balusters are turned out quicker this way than on lathes. A Vermont company completes in 1 hr. a baluster 3½ ft. long and 6 in. greatest diameter. Carborundum saws are also used in fluting marble columns.

20. Properties, Distribution, and Uses of the Most Important Building Stones.

20a. Igneous Rocks.—Many kinds are used in structural work. Among the harder denser ones, the granites find greatest favor because of abundance, lighter color, and structural features in the quarry. Syenites and diorites are rare and in little demand. They possess no advantage over granite. Gabbros are too dark to suit most architects but occasionally are of value for decorative purposes. Diabase is hard and not usually obtainable in large blocks, but has been used for paving.

The volcanic rocks, including many lavas and tuffs, are abundant in the far west and Mexico. They are often porous and soft and adapted for work in a dry climate above ground. The granites deserve special mention.

Granite.—This term is sometimes rather loosely used and may even include gneiss. Diabase and gabbro are sometimes called black granite. Only granites proper are here considered.

They show the following properties: *texture*—coarse to fine, sometimes porphyritic; *color*—red, pink, white, gray, and intermediate shades; *crushing strength*—good, average range 15,000 to 30,000 lb. per sq. in.; *modulus of rupture*—average of a number of tests, 1420 to 2410, another set gave 2480—3382; *elasticity*—rarely tested, one set tested in pieces of 20-in. length, and 5.5 in. diameter at middle showing compression of 0.0108 to 0.0243 in. under load of 5000 lb. per sq. in. with a lateral expansion of from 0.005 to 0.007 in.; *porosity*—always small, and absorption usually under 1%; *fire resistance*—not good, spalls easily under combined effects of fire and cold water; *weight per cu. ft.*—165 to 170 lb.; *specific gravity*—about 2.66, which is equivalent to 2 long tons or 4480 lb.per cu. yd.

Uses.—Granite has a wide variety of uses on account of durability, textural and color variations. Coarser and medium grained varieties are best for massive work, and the finer and even textured ones for monumental and decorative uses. Many take a high and durable polish, and darker ones often give excellent contrast.

Distribution of Igneous Rocks in the United States—Eastern Belt.—Extends from Maine to Georgia. The most productive region of the United States supplying granite of varied color and texture. The quarries of Maine often located along coast where shipments can be made by water. Those of Vinal Haven and Hurricane Island, Me., Barre, Vt., Concord, N. H., Cape Ann, Quincy and Milford, Mass., Stony Creek, Conn., Mount Airy, N. C., and Stone Mountain, Ga., are especially well known. Some, like Port Deposit, Md., have a gneissic structure. Windsor, Vt., supplies a magnificent green granite. The Quincy, Mass. and Westerly, R. I., are noted for monumental work. A variety of gabbro quarried in the Adirondack Mountains of New York is also of ornamental value. Diabase is extensively quarried in the Palisades of the Hudson for road material and paving blocks.

Wisconsin-Minnesota Area.—Many good granites occur in these two states. The Montello of Wisconsin is a splendid red for polished monumental work. St. Cloud and Ortonville, Minn., are likewise well known.

Southwestern Area.—This includes the pink granites of southeastern Missouri, the syenites near Little Rock, Ark., and Wichita and Arbuckle Mountain districts of Oklahoma, and some small areas of excellent granite in Llano and Burnett Counties, Tex.

Cordilleran Area.—This supplies excellent granites in the Sierra Nevada belt of California, and many volcanic rocks adapted for structural work in the area to the east. Granites and gneisses occur in the Rocky Mountains but are little used.

Canada.—The provinces of Quebec, Ontario, and British Columbia contain a number of excellent granites. Some excellent volcanics are also quarried on Vancouver Island.

20b. Sandstones.—*Texture*—ranges from coarse to fine, the former passing into conglomerates and the latter by increase of clay into shale; *hardness*—variable, and dependent on nature and quantity of cement, the strongly cemented, dense siliceous ones being called quartzite; *color*—variable, commonly due to iron cement giving reds, browns, and yellows, while clay or organic matter will often give gray; *absorption*—shows wide range, the hard dense ones like quartzites showing under 1%, while more porous ones run as high as 10%; *mineral impurities*—pyrite and sometimes mica, the latter if abundant along bedding planes, causing stone to split under frost action; *crushing strength*—shows average range of 9000 to 20,000 lb. per sq. in., or higher, but quartzites may run much higher; *transverse strength*—a set of 10 from Ontario showed a modulus of rupture ranging from 417 to 2186 lb. per sq. in.; *specific gravity*—about 2.6; *apparent specific gravity*—from about 1.8 to 2.7; *weight per cu. ft.*—from as low as 113 to as high as 170, depending on porosity; *porosity*—ranges from 2% to over 15%; *fire resistance*—fairly good except in dense stones.

Uses.—These include structural uses, as for dimension block, carved stone, steps, floor tile, paving blocks, grave vaults, concrete, road material, grindstones, glass sand, and silica brick. Some of these, especially the last three, call for stone of special qualities.

Varities.—*Arkose*, composed chiefly of feldspar grains; *Bluestone*, a flagstone much quarried in eastern New York, but the name is applied also to many other bluish gray sandstones; *Brownstone*, a brown sandstone formerly much quarried in Connecticut Valley, but the name has lost its geographic significance; *Freestone*, a sandstone which splits freely and dresses easily;

Graywacke, a hard compact sandstone, composed of grains of feldspar, quartz, slate, and perhaps other minerals with a clayey cement.

Distribution of Sandstones and Quartzites.—Sandstones especially are very widely distributed in many parts of the United States and Canada. The most important in the former is the Berea quarried in northern Ohio and shipped to many points both east and west. Many good ones are quarried in Canada.

20c. Limestones.—*Mineral composition*—may be either calcitic or dolomitic but the two grade into each other; *mineral impurities*—pyrite in many and undesirable on account of its weathering to limonite, chert not uncommon in some but is undesirable because it weathers out as knots and may cause stone to split on exposure to weather, or interfere with drilling, and cutting; *color*—various shades of blue, gray, black, and white; *hardness*—ranges from soft porous ones, like those of Bermuda or Caen, France, easily cut with saw, to dense massive varieties; *texture*—usually fine grained but sometimes coarse; *absorption*—usually under 2% but some may run as high as 10 to 12%; *crushing strength*—shows wide range, a series of 34 Canadian ones running from 8000 to 37,000; *transverse strength*—variable, some being as low as 800 and others as high as 4000, with 2000 about the average modulus of rupture; *fire resistance*—fair, at temperatures below that required to convert the stone into quicklime.

Varieties of Limestone.—*Chalk*—fine white earthy limestone, not of much use for building; *Coquina*—a loosely cemented shell aggregate found near St. Augustine, Fla.; *Dolomite*—a rock containing the mineral dolomite as the chief carbonate; *Hydraulic limestone*—one containing sufficient clayey impurities to be used for making cement; *Oolitic limestone*— one made up of small rounded grains, the Bedford, Ind., limestone and some French ones used for structural work being of this character; *Travertine* or *calcareous tufa*—a porous limestone deposited by spring waters and sometimes sufficiently hard and compact for building —that quarried near Rome, Italy, is exported to the United States for interior work in walls and floors.

Uses.—Limestones are widely used for all kinds of structural and decorative work, the denser harder varieties taking a polish, and sometimes called marble in the trade Much is used for lime and cement, road material, blast furnace flux, and in the chemical industries. There is thus a market often for the waste stone.

Distribution.—Limestones are so widely distributed that few quarrying districts do more than supply a local demand. One exception is the Bedford, Indiana, area whose product is shipped to many points in the United States and Canada. Canada contains many limestone deposits of excellent character. Not a few decorative limestones are imported, these including the Caen, Normandie, and Hauteville stones of France and the Roman travertine.

20d. Marbles.—This term properly includes those limestones and dolomites of crystalline texture, dense character, and susceptibility of taking a good polish. *Mineral composition*—when pure, calcite or dolomite or a mixture of the two—accessory minerals may be graphite or mica, often arranged in patches or bands thus giving a decorative effect—serpentine may be present in some; *mineral impurities*—pyrite found in any kind, tremolite in dolomitic marbles, chert in some; *structure*—this may be massive, banded, or brecciated, the interspaces of the latter often being filled by coloring cement which adds greatly to the stones decorative value; *weathering qualities*—many massive marbles show excellent durability but the presence of bands of mica or other silicates, or brecciated structure detracts from the life of the stone if exposed to a frosty climate; *color*—shows wide range, white, gray, black, red, yellow, brown, pink, etc.; *texture*—from coarse to fine; *absorption*—always low, usually under 1%; *crushing strength*—averages about 15,000 lb. per sq. in. or more; *actual specific gravity*—2.7 to 2.9, dolomite marbles being heavier than calcite ones—marbles weigh from 165 to 180 lb. per cu. ft.

Uses.—Massive, sound marbles of varying texture may be used for ordinary structural work or even coarser carving; fine-grained, even-textured and usually even-colored types for statuary; colored, clouded, banded, and brecciated forms much employed for interior decoration. By matching slabs of banded marble together, highly decorative patterns are sometimes obtained. The massive ones containing only carbonate minerals, usually take a more continuous polish. Slabs are frequently used for floor tiling but the mistake is often made of setting pieces of different abrasive resistance side by side. In localities where there is much passing, the floor rapidly gets uneven.

Distribution in United States.—The Eastern belt, from northern Vermont to Alabama, supplies a great variety of marbles. Noteworthy are the variegated hard siliceous ones of Swanton, widely used for flooring; the white, gray, and green veined, banded, and clouded ones of western Vermont; the pink and brown of Tennessee for flooring, wainscoting, and structural work; and the white coarse texture, as gray and white of Georgia, for structural work, interior decoration, and monuments. Black marbles are quarried in Virginia. Some white and streaked marbles are quarried in Colorado, and white or banded ones in California. Many highly ornamental marbles are quarried in Quebec and also British Columbia.

Serpentine Marble.—Massive rock composed largely of the mineral serpentine, but containing varying quantities of such impurities, as iron oxides, pyrite, hornblende, pyroxene, and carbonates of lime and magnesia. The color is often green or greenish yellow, but others are various shades of black, red, or brown.

It is one of the most decorative stones known but often difficult to obtain in large slabs on account of the frequent and irregular joints in the quarries. Most serpentines are also unsafe for exterior use in a severe climate as they lose their polish and break along the veins that often traverse them. Comparatively little serpentine is quarried in the United States. That from Roxbury, Vt. is one of the best known. Another known as *verdolite* is obtained near Easton, Pa., and others from Maryland and Georgia. Much is imported especially from Greece.

Onyx Marble.—A calcareous rock of crystalline texture, high translucency, and usually ornamented by veins and cloudings of iron oxide. It is much used for special decorative work and is a stone of great beauty. It should not be exposed to the weather or abrasion. Mexico has contributed much onyx to the trade as has also Egypt.

20e. Slate.—Slates are divided into clay slates and mica slates, the latter being the more abundant. These may in turn be subdivided into fading slates of black, green, or purplish color, and unfading ones of black, red, green, or purplish color. Mica slates possess greater strength and elasticity.

Structure—Slaty cleavage is the most important property—bate, or false cleavage is a minute plication resulting in microscopic slips or faults along which the slate breaks easily; *mineral impurities*—pyrite in lumps and grains may be present, and causes rejection of the slate—quartz and calcite veins also are undesirable—magnetite should be absent if the slate is to be used for electrical work. *Color*—as stated above; *texture*—fine grained; *transverse strength*—in best slates, modulus of rupture is 7000 to 10,000 lb. per sq. in.; *elasticity*—as measured by deflection of a slab set on supports 22 in. apart, about 0.27 to 0.313 in.; *specific gravity*—2.7; *absorption*—under 1 %.

Uses.—Thinly cleaving slate is used for roofing. Thick slabs, known as mill stock, are used for stair treads, toilet partitions, shower baths, urinals, floor tile, switchboards, sinks, tubs, blackboards, etc. Roofing slates have usually ranged from 1/4 to 1/6 in. in thickness, depending on size, but modern practice has standardized the thickness at 3/16 in. for commercial grades. Thicker slates are produced for what are known as architectural roofs.

The price and measurement of slate are figured by the square (100 sq. ft.). The number of slates required for a square can be determined by the formula:

$$n = \frac{28,800}{bd - bl}$$

in which n = number of slates in square, b = width of slate, d = length of slate, and l = overlap in inches.

Roofing slate is trimmed with the lower edge parallel to the grain.

Although slate makes a durable roofing material, in recent years it has had serious competitors in burned clay tile and various artificial roofing materials, such as asbestos shingles.

Distribution.—Most of the slate quarried in the United States is obtained from the East, Maine, Vermont, New York, Pennsylvania, and Maryland being important producers. Some is obtained from Arkansas and California. The known localities of good slate are limited, for the stone to be salable and durable must meet rather severe requirement. A little is quarried in Canada.

BRICK

By D. Knickerbacker Boyd

Brick is adapted to a variety of uses in the construction of buildings, being used for exterior and interior walls, fireproofing, backing up other materials, and decorative effects. The possibilities for artistic treatment of wall surfaces are not even limited by the wide range of color and texture of brick, for with the use of a given brick, wide variations in color effect and texture may be obtained by varying the size, design, and color of the mortar joint. For example, a raked-out gray mortar joint will not only give a rougher texture to a wall but will also give a darker color effect than if the same mortar be cut flush with the face of the same brick.

The word "brick," as ordinarily used, refers to a rectangular prism of clay, shale (a form of clay), or a combination of these burned in a kiln. Until comparatively recent years, practically all brick were burned-clay brick. Brick, however, is now made in which the base is of other material than clay, and when such units are referred to, a descriptive prefix should be used in connection with the word brick, such as firebrick, slag brick, silica brick, cement brick, sand-lime brick, etc.

21. Classes of Brick.—Commercially, brick may be divided into four general classes—building brick, sewer brick, paving brick, and refractory brick.

Building brick are the various kinds of brick usually employed in construction work. In addition to "common" brick and "face" brick, such brick as cement brick, sand-lime brick, etc., are used in some localities. The usual building brick, made from clay, may be broadly classified as common brick and face brick.

Sewer brick are usually the "common" building or shale brick indigenous to the locality, sometimes being selected for especial qualities (see A.S.T.M. specification for clay sewer brick).

Paving brick are especially manufactured for the purpose and are burned to vitrification. They are sometimes used in building construction for particular effects or purposes.

Refractory brick are designed primarily to meet special conditions of use, such as resistance to the action of fire and gases at high temperature, etc. They include the various kinds of fire brick and such special brick as silica, ganister, basic, and chrome brick. These latter find their largest use as linings for various industrial furnaces. The American Society for Testing Materials and the Refractory Brick Manufacturers Association have published detailed descriptions of results of tests and recommended uses for the various kinds of refractory brick, and the latter association has issued several illustrated sheets and charts for standards for this type of brick including those of radial shape.

Common brick is the brick most extensively used for the construction of walls, piers, etc.; for backing up stone and terra cotta; and for fireproofing of steel and iron. In the East, it is usually red—the depth of color, however, depending on the composition of the clay, the method of manufacture, and the degree of burning. In the Middle West, common brick is usually yellow; and in other sections of the country, the color varies with the clays.

Face brick are the brick used on the exposed surfaces of walls, piers, etc. Common brick are also used as face brick, in which case the bricks of the desired character for the effect to be obtained are usually selected either at the kiln or from those intended for the solid wall as laid. As the term "face" brick is generally understood, however, through commercial usage, it means a brick especially made for its color, surface texture, and regularity of size, as may be required to produce the desired effect on surfaces exposed to view.

22. Color of Brick.—Brick may be obtained in practically any color, the color depending principally on the presence of various chemicals, coloring matter, etc., in the clay. The usual colors are red, buff, gray, iron spot, and manganese spot. Perfectly white brick can be obtained only by the use of surface glazes or enamels, but light-gray or cream brick can be produced from various mixtures of clay and chalk or from certain marls.

Among the principal materials affecting the color of the brick are iron, lime, and magnesia. Oxide of iron produces a bright red; magnesia, a brown; and magnesia and iron, a drab. Mineral coloring matter, especially in connection with dry-pressed brick, is sometimes added to the clay. In addition to the colors themselves, the following expressions are in general use: "clear color," a brick with a clear color and without flash; "fire flashed," a brick which has been subjected to a reducing action of the fire, thereby bringing out the iron in the clay and producing darker colors on the faces and heads of the brick than is produced in the interior of the brick.

23. Raw Materials.—The basic materials of which ordinary building brick are made are clay, silicate of alumina or shale, and, in smaller and varying quantities, silica (sand or quartz), oxide of iron, lime, and, possibly, some magnesia, potash, and soda.

For face brick the clay is usually very carefully selected, and often several clays of different compositions are mixed to obtain the desired result.

Clay.—Pure clay or kaolin is white, and the best qualities are used principally in the manufacture of china and porcelain. The clay used for brickmaking is usually the "surface" material. It generally contains sand (silica) and small quantities of iron oxide, lime, and magnesia.

Clay for making vitrified brick should be fusible, plastic, and able to be heated to high temperature without losing its shape.

Shale.—Brick are also made of shale. . This is the natural, soft rock from which clay is produced by decomposition. Generally, it makes a harder brick than ordinary clay.

Sand (Silica).—Sand, if not normally present in sufficient quantities, is added to the clay to prevent cracking, shrinking, and warping and also to allow a partial vitrification of the material. The larger the proportion of sand the more uniform in texture and shape will be the brick, but if used in too large quantity it will cause the brick to be weak and brittle.

Oxide of Iron.—Oxide of iron acts as a flux, increases the hardness, and gives the brick a red color.

Lime.—Lime acts as a flux and lessens the shrinkage of the brick in drying. The lime should be present in a finely divided state, as lumps of lime constitute a serious defect.

Magnesia, Potash, and Soda.—These act as a flux in burning, thereby causing the grains of silica to melt and bind the various particles together.

24. Manufacture of Brick.—Bricks are made by first properly preparing the clay and then forming it to the required shape. After drying until sufficiently hard to be stacked in the kiln, the bricks are "burned" at a temperature usually about 2000 deg. F.

The characteristics of brick are largely dependent upon the clay used, the method of manufacture employed, and the degree of burning.

According to the methods employed in making, brick are known as soft-mud brick, stiff-mud brick, dry-pressed brick, repressed brick, machine brick, and handmade brick.

According to the degree of burning and location in the kiln, common brick are generally known as arch or clinker brick, body, cherry, or hard brick, and salmon, pale, or soft brick.

Soft-mud Brick.—Soft-mud brick are molded either by hand or machine from clay which has been reduced by the addition of water to a soft and plastic mass. Handmade brick are practically all made by this process.

Stiff-mud Brick.—In the manufacture of stiff-mud brick, only enough water is added to make the clay plastic. This stiff mud is then forced through a die by machinery and is automatically cut to the required size. They are known as end cut or side cut, according as the cut is on the ends or on the sides of the brick. These brick are usually distinguished from soft or pressed in that the cut surfaces have a rough texture and the other surfaces are smooth. They are always machine made and are sometimes known as wire-cut brick.

Good brick can be made by either the wet or the stiff-mud process, and their relative qualities vary in different sections of the country.

Dry-pressed Brick.—These are sometimes referred to as pressed brick. They are machine molded from dampened clay, are practically always used for face work, and include the various hydraulic pressed brick.

Repressed Brick.—Usually a stiff-mud brick repressed in a press box before burning. The brick is thereby made much more regular in shape but with consequent increase in the cost. Soft-mud brick, after being partially dried, are occasionally repressed, a process that greatly improves the form and increases the strength of the brick, but more frequently the term "repressed" refers to a repressed stiff-mud brick. Repressed brick are sometimes incorrectly called pressed brick.

Machine-made Brick.—Any brick not handmade. As all brick may be machine made and as all but soft mud-brick are machine made, the term is indefinite.

Handmade Brick.—The soft-mud brick are the only handmade brick.

Arch or Clinker Brick.—These are the brick which adjoin the firing spaces and being subjected to extreme heat are harder and more irregular in shape and color than any of the others. In some cases, they are partly vitrified and almost black in color on one or more faces.

Body, Cherry, or Hard Brick.—These are the most regular in shape and color of the brick taken from the kiln. They are neither over- nor underburned and constitute the major portion of the brick from each kiln.

Salmon, Pale, or Soft Brick.—These are underburned, being remote from the fire. They have not sufficient hardness or strength to warrant their use alone in exposed places, piers, or load-bearing walls involving any considerable weight. They may be used in connection with hard brick for filling and backing up.

The terms "salmon" and "pale" refer to the color of the brick and, hence, are not applicable to a brick made of clay that does not burn red. In most instances, the clay used for making common building brick burns red, but the localities in which this is not the case are sufficiently numerous to make it desirable to use a different term in designating this quality of brick.

Smooth Brick.—A brick of any of the above types having a relatively smooth surface on its face and ends.

Water-struck Brick (Slop Brick).—A brick of the soft-mud type, the mold having been dipped into water just before being filled with clay. They are usually made by hand and, in any case, are more or less irregular in shape and color, and the surface is comparatively smooth.

Sand-struck Brick (Sanded Brick).—A brick, usually of the soft-mud type, coated while molding on its face and ends with sand. The sand is placed in the molds both to prevent the brick from sticking and to give the desired surface effect.

Rough-texture Brick.—A brick having an artificially roughed surface. Some are irregular in conformation and others have ridges and valleys extending in a vertical or horizontal direction on exposed faces. The brick is usually, but not necessarily, of the stiff-mud, wire-cut type, and many of them are given trade names descriptive of the texture.

25. Classification of Brick according to Physical Properties.—In 1919, the American Society for Testing Materials adopted the report of Committee C-3 on brick which classified brick as vitrified, hard, medium, and soft on the basis of physical requirements for *absorption*, *compressive strength* of brick on edge, and *modulus of rupture*. The standing of any set of bricks was determined by that one of the three requirements in which it was the lowest. The table for this classification was published in the previous edition of this Handbook.

In t[illegible] it was realized that this table was not based on the latest available results of tests on bricks and brickwork which had disclosed much new information. Committee C-3, therefore, undertook the revision of the specifications and, in table presented to the society for adoption, as tentative, a new specification for building brick (made of clay or shale).

The table included in the specification for the classification of such brick and which is the result of 2 years of study on the part of Committee C-3 on brick is given below. In this it will be noted that absorption is not longer included as a factor in determining the grade.

Name of grade	Ultimate compressive strength, pounds per square inch, bricks flatwise		Modulus of rupture, pounds per inch, bricks flatwise	
	Mean of five tests	Individual minimum	Mean of five tests	Individual minimum
Grade A	4500 or over	3500	600 or over	400
Grade B	2500 to 4500	2000	450 or over	300
Grade C	1250 to 2500	1000	300 or over	200

NOTE.—The above classifications are based on strength and do not necessarily measure weather resistance. The tests shall be conducted in accordance with Tentative Methods of Testing Brick, Serial Designation C67-28T, of the American Society for Testing Materials.

26. Quality and Crushing Strength of Brick.—Theoretically, a brick of the very best quality should be regular and true in shape and free from kiln marks or depression caused by pressure of the brick above it in the kiln. It should be well burned throughout, free from lumps of lime, large pebbles, air bubbles, or fissures, of firm, compact texture, and fairly even in color. It should give a clear ringing sound when struck a sharp blow with a hammer or against another brick.

For most purposes it is not necessary to require a brick possessing all of these qualities, a fairly regular well-burned brick being usually sufficient unless uniformity is desired as in some kinds of "face" work. The various standards of quality, moreover, depend upon the kind of brick and the method of manufacture employed.

The crushing strength of brick (and the modulus of rupture), as given in the preceding classification table, is valuable in comparing different brands or makes but does not accurately represent the strength of the brick masonry, as this strength is dependent on the strength of the mortar and care in laying. The results of tests heretofore available have been chiefly on individual bricks and on piers. In 19[illegible]5 and 1[illegible]7, however, the Common Brick Manufacturers Association and the Bureau of Standards conducted an extensive series of tests on large brick walls. (For tests on brick, brick walls, and brick piers, see Appendix *II*.) Maximum safe loads for brick masonry are given in Appendix *I*.

27. Size of Brick.—The Division of Simplified Practice of the Department of Commerce, in 1923, called a general conference of manufacturers, distributers, and users of face brick and

common brick, and as the result of the unanimous action of this conference the Department of Commerce through the Bureau of Standards recommended that recognized approximate dimensions of the above types of bricks should conform to the following:

APPROXIMATE DIMENSIONS, INCHES

Types	Length	Thickness	Width
Common brick	8	2¼	3¾
Rough-face brick	8	2¼	3¾
Smooth-face brick	8	2¼	3⅞

It must be understood that these standard sizes are based on the size of an average burned brick and are intended to represent close approximate or average sizes rather than absolute fixed dimensions to which no variation is allowed. Any layout which allows for ample jointing will take care of small variations in size. In burning, the brick shrinks from the size in which it was originally formed; and since the exact amount of the shrinkage depends on the composition and kind of raw materials and on the degree of burning, it is commercially impractical to make every brick, even with the same method of manufacture, of exactly the same size. The harder burned brick will average smaller than the softer or underburned brick, and clay from different portions of the same clay bank will sometimes vary in the amount of shrinkage, but all reputable manufacturers will naturally attempt to conform to the recognized standard size. According to the 1927 specification of the A.S.T.M., the plus or minus variation from the standard size permitted is 1⁄16 in. in thickness, ⅛ in. in width, and ¼ in. in length.

Size of Roman Brick.—The National Brick Manufacturings Association in 1889 adopted a size of 1½ × 4 × 12 in. for Roman brick.

Size of Norman Brick.—The National Brick Manufacturings Association adopted a size of 2¾ × 4 × 12 in. for Norman brick.

Size of Enameled Brick.—The usual sizes of enameled brick as listed by some of the largest manufacturers are as follows:

Standard size	2¼ × 4 × 8¼ in.
Roman size	1½ × 3⅞ × 11⅝ in.
English size	2⅞ × 4⅜ × 8⅞ in.
Norman size	2¼ × 4 × 11¾ in.
Split size	1⅛ × 4 × 8 in.

28. Sand-lime Brick.—Sand lime brick are of two classes—lime-mortar brick, in which the cementing material is carbonate of lime, and sand-lime brick in which silicate of lime forms one of the cementing materials.

Lime-mortar brick is the older form of sand-lime brick and was used only in a small way even where sand and lime were cheap and clay brick were scarce. It is virtually a lime mortar, molded into the shape of a brick, hardened in the open air in connection with carbon dioxide either with or without pressure.

Sand-line brick are made from an intimate mixture of sand or granular silicate and hydrated calcium lime. These two materials are mixed in the proportion of about 6 to 10 parts of sand to 1 of hydrated lime, molded in a press, and hardened in a large cylinder filled with steam at 100- to 150-lb. pressure.

The bonding is the result of the formation of calcium silicate, calcium magnesium silicate, or calcium hydrosilicate to the action of the steam upon the sand.

This form of sand-lime brick is the only one to which the term now applies.

The natural color of sand-lime brick is whitish, light gray, or pink varying to some extent according to the color of the sand used. Other colors may be obtained by the use of inert mineral oxides, but these affect the quality of the brick, in proportion to the quantity of the coloring material required.

The quality of sand-lime brick depends largely on the proper selection of the sand and lime and upon care in manufacture. The sand should be pure silica sand containing a large proportion of fine grains. Clay or kaolin tends to weaken the brick, and not more than 10 % should be permitted.

Technologic Paper No. 85 of the Bureau of Standards, published in 1919, on the "Manufacture and Properties of Sand-lime Brick," gives a complete description of this product; and in Technologic Paper No. 276 of the same

bureau, entitled "Compressive Strength of Sand-lime Brick Walls," will be found complete descriptions and illustrations of a series of tests concluded in 1924.

29. Cement Brick.—Cement brick or concrete brick or cinder brick, as they are also called, are made either by hand or by machine. The binding material should, of course, be Portland cement and according to the Tentative Specifications for Concrete Building Brick of the American Society for Testing Materials, as offered by Committee C-3 on brick, in 1927 the aggregate "must consist of sand, gravel, crushed stone, crushed blast-furnace slag, steam-boiler cinders, or other equivalent material graded from fine to coarse. No proportions are given, it being assumed that each reputable manufacturer will so compound the brick and proportion the cement to the aggregate as to produce a unit that will satisfactorily meet the requirements stipulated for intended use. According to the same specification "when sampled at the plant the age of concrete bricks when tested shall be at least 28 days." To ensure uniformity of product and compliance with strength requirements, tests should also be made from time to time on brick delivered at the job.

Coloring matter is sometimes mixed with the cement and sand. Various textures and colors can be obtained by the use of different aggregates and by brushing the surface with water or acid before the cement has set. Cement bricks for face purposes are also made by a proprietary process.

30. Slag Brick.—Slag brick are made from a mixture of basic slag and slaked lime. The silica in the slag usually ranges from 22 to 35%, the alumina and iron oxide together from 16 to 21%, and the lime from 40 to 51%. In the manufacture, the granulated slag is dried and pulverized and the powdered slaked or hydrated lime is added, usually with a small amount of water. This mixture is then molded into shape either by hand or by machine and dried for from 6 to 10 days in the open air.

31. Fire-clay Brick.—In the manufacture of fire-clay brick, certain clays, one of which is a plastic clay serving as a skeleton for the brick, are burned until partial vitrification occurs. The principal kinds of brick in the manufacture of which fire clay plays an important part are fire brick, paving brick, acid-proof brick, and glazed brick.

32. Fire Brick. Fire bricks are used for the linings of fireplaces, back hearths, boiler stacks, linings of fire boxes in heating and power boilers, and wherever resistance to the effects of high temperature is a prime consideration. They are generally made of a mixture of flint and plastic clay, are white or white and brown in color, and are graded as first and second quality. The first grade has the higher fuse point, is softer, and is of less compressive strength than the second grade.

The expansion and contraction of fire brick is dependent upon the relative proportions of silica to alumina, and most of these brick contain sufficient alumina to show some contraction.

33. Paving Brick or Blocks.—A very hard ordinary clay brick is sometimes referred to and used as a paving brick, but the brick or blocks here described are made from a mixture of the more siliceous shales (a fine-grained indurated clay) and fire clay. These are crushed and screened, molded or cut to the required size and shape, dried, and then burned for from 7 to 10 days at a temperature from 1500 deg. F. to a point of vitrification and annealed or toughened by slow cooling. In this way, a tougher, denser, and stronger brick is made than is possible with ordinary clay or kaolin.

A vitrified block, larger than the ordinary brick, is made especially for street paving and is commonly referred to as a brick paving block.

Paving brick or blocks are made with plane faces and also with projections so designed that there will always be a space between the faces of the brick when laid. Some machines cut the brick with lugs on one side and grooves on the other, and others repress the brick, forming lugs, grooves, rounded edges, etc., by the die in repressing.

One of the first conferences called by the Division of Simplified Practice of the Department of Commerce was to reduce the many sizes then prevailing of paving brick. In successive years, reduction has taken place by unanimous consent, until, in 1927, the following five kinds and sizes became the standards obtaining in Class A, vitrified paving brick—subject to plus or minus variation of ⅛ in. in width and depth and ¼ in. in length:

Kind	Depth	Width	Length
1. Plain wire cut (vertical fiber lugless as usually laid)	2½	4	8½
2. Plain wire cut (vertical fiber lugless as usually laid)	3	4	8½
3. Plain wire cut (vertical fiber lugless as usually laid)	3½	4	8½
4. Wire cut lug (Dunn)	4	3½	8½
5. Repressed lug	4	3½	8½

These sizes are stipulated in the Tentative Specifications for Paving Brick of the American Society for Testing Materials, 1927, in which and in the Standard Methods of Test for Brick are given the rattler test and loss determinations for establishing qualities.

Vitrified paving brick, while primarily designed for street paving, are also used, to some extent, in connection with building, being adapted for use for floors, wainscotings in industrial buildings, and even special decorative effects.

34. Enameled Brick.—The body of an enameled brick, usually of fire clay, is coated on one or two sides with an opaque enamel.

There are two methods of applying enamel. According to one, the enamel is applied directly to the face of the brick; according to the other, the more common method in this country, a transparent glaze is applied over a white or colored "slip," the slip coming between the glaze and the face of the brick.

Enameled brick may be obtained in white and a large number of colors and in two surface finishes—highly glazed and dull or satin glaze. They are used for face work both for interior and exterior walls, especially where reflection of light, such as in light courts and shafts, and cleanliness are prime considerations. They are also used to a considerable extent for facing tunnels, engine and boiler rooms, store fronts, etc., but should never be placed where dampness is liable to attack them from the back.

The terms "glazed" and "enameled" are sometimes both used to refer to the opaque enameled brick. The true glazed brick, however, is also referred to as "salt glazed."

35. Glazed Brick.—Glazed brick are made of a fire clay containing felspar, flint, and whiting and may be obtained in various shades. They are fired at a high temperature until the surface is coated with a transparent glass or glaze. In the manufacture of salt-glazed brick, salt is introduced into the kiln during the process of burning.

Salt-glazed brick are used to a considerable extent for facing areas, garages, market houses, dairies, domestic science rooms, wainscotings, face brickwork, etc., and, being non-absorbent and easily cleaned, are especially adapted wherever cleanliness and sanitary conditions are of prime importance.

36. Patented Interlocking Brick.—There have been placed on the market in recent years several types of interlocking brick, providing in walls a series of isolated air spaces which serve as temperature and moisture insulators. Their makers claim for them a heat-transmission ability of from 40 to 60% less than frame, or 25 to 50% less than solid brick or hollow-tile construction.

No ties or headers are necessary or used with the brick, except at openings and corners, etc. Plastering is usually recommended to be applied directly to the inside surface, without furring, in which case it is necessary to exercise special care at openings and use calking and waterproofing. These brick are either 8 or 12 in. wide and about 8 × 2¼ in. on the face, and, as laid, each brick represents the full thickness of the wall. Webs made integral with the brick hold the inner and outer walls together. Offsets on upper and lower surfaces hold the bricks in alignment, laying in mortar being done in various manners claimed to result in less consumption than with solid walls. The standard brick should be laid in running bond. English, Flemish, or Dutch bond may be had by using specially cut brick, but the cost of these is higher.

STRUCTURAL CLAY TILE

By H. Ray Kingsley

In the past and, to a considerable extent, at the present time, structural clay tile has been variously known as tile, hollow terra cotta, hollow building tile, terra-cotta tile, structural terra cotta, and terra cotta. To the structural clay tile industry there is only one name used at

present to cover this material, namely, "structural clay tile," which covers all structural hollow burned-clay tile shapes. The term "terra cotta," which is applied to ornamental building units of burned clay, should not be used to designate structural clay tile. The term "structural clay tile" is understood to mean the hollow burned-clay material used for the construction of walls, partitions, foundations, floors, roofs, ceilings, furring, and fireproofing purposes. On account of its adaptability to a larger variety of uses, its lightness, combined with great compressive and transverse strength, its fireproof qualities, its resistance to atmospheric conditions, its sealed hollow cells which provide a very high degree of resistance to passage of heat, and its general availability, it has become a widely used building material.

The shell of a tile is its outer walls, the webs are the partitions dividing the tile into cells, and the cells are the openings parallel with the shell and webs.

The scoring is the grooves formed in the exterior faces of the shell to increase the bond of mortar, plaster, or stucco.

In referring to the dimensions of a tile, the length is the dimension between the cut ends; the thickness is the dimension at right angles to the face of the wall, floor, or other member in which the tile is used; and the width is the dimension at right angles to the thickness and length. In practice, the first dimension given is thickness; the second, width; and the third, length.

37. Kinds of Structural Clay Tile.—

1. *Load-bearing Tile.*
   (a) Load-bearing wall tile.
   (b) Hollow floor tile.
   (c) Foundation tile.
   (d) Side-construction tile. A tile designed to receive its principal stress at right angles to the direction of its cells.
   (e) End-construction tile. A tile designed to receive its principal stress parallel to the direction of its cells.
2. *Non-load-bearing Tile.*
   (a) Split tile. A hollow tile which has been knifed parallel with its cells in the process of manufacture for the purpose of separation into two equal units.
   (b) Partition tile.
   (c) Furring tile. A tile used for lining the inside of walls and carrying no superimposed load.
   (d) Porous hollow tile. A clay hollow tile in which the natural porosity of the clay has been increased by the admixture of other ingredients.
3. *Book Tile.*—A tile with tongue-and-groove edges resembling a book in shape.
4. *Salt-glazed Tile.*—A tile with a vitreous glaze on its surfaces produced by burning salt in the kiln at the temperature used in finishing the burning. This tile, when the glazing is unbroken, is impervious to moisture and is unaffected by most acids, chemicals, alkali, marsh water, vegetable oils, gases, and other agents.
5. *Face Tile.*—Face tile is made from the same materials as a high-grade face brick, maintaining the same various face textures and colors. The finish may be either glazed or unglazed and with a smooth or a rugged surface. The use of colored mortar joints in face-tile walls adds greatly to the appearance.

38. Manufacture.—The raw material from which structural clay tile is manufactured is a clay[1] or mixture of several clays from the following sources: *shale*, a thinly stratified, consolidated sedimentary clay[1] with well-marked cleavage parallel to the bedding; *fire clay*, a sedimentary clay of low flux content, which is usually found associated with coal measures; *surface clay*, an unconsolidated, unstratified clay, occurring on the surface.

The clay is pulverized, mixed with water to the proper consistency, forced through a die which determines its shape, and then cut into the proper lengths. The tile are then stored in a drying room and, after proper drying, are moved to a specially constructed kiln where they are burned at temperatures ranging from 1700 to 2400 deg. F. Due to the different kinds of clay used, there is a variety of color in hollow tile. Color cannot be taken as indicative of the strength of the tile.

The exterior surfaces of the tile, except where intended to be exposed to view, are scratched or grooved to afford a key for plaster or stucco. In addition to the mechanical bond thus provided, hollow tile has a very strong natural bond. There is no better surface upon which plaster and stucco may be applied.

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[1] The definitions for the terms "surface clay," "fire clay," and "shale" are based upon the following definition for the term "clay":

Clay.—An earthy or stony mineral aggregate consisting essentially of hydrous silicates of alumina, plastic when sufficiently pulverised and wetted, rigid when dry, and vitreous when burned at a sufficiently high temperature.

39. Specification Requirements.—The following specification requirements are taken from the A.S.T.M. Standard Specifications and Tests for Hollow Burned-clay Load-Bearing Wall Tile (C34-27), Tentative Specifications and Tests for Hollow Burned-clay Fireproofing, Partition and Furring Tile (C56-27), and Tentative Specifications and Tests for Hollow Burned-clay Floor Tile (C57-27). The specifications are for tile made from surface clay, shale, fire clay, or admixtures thereof.

Classification. According to the results of physical tests the tile shall be classified as hard, medium, or soft on the basis of both strength and absorption requirements for any given kind and class.

Strength and Absorption Requirements.

STRUCTURAL BURNED-CLAY LOAD-BEARING WALL TILE

Class	Absorption, per cent		Compressive strength, based on gross area, pounds per square inch			
			End construction		Side construction	
	Mean of five tests	Individual maximum	Mean of five tests	Individual minimum	Mean of five tests	Individual minimum
Hard	12 or less	15	2000 or more	1400	1000 or more	700
Medium	16 or less	19	1400 or more	1000	700 or more	500
Soft	25 or less	28	1000 or more	700	500 or more	350

Gross area shall be taken as the total area enclosed by the outside dimensions of the unit taken in a direction perpendicular to that in which the load is carried.

Where end-construction tile are used on the side, they shall meet the requirements of that construction, and vice versa.

All tile shall be so designed that substantially the same masonry strength will be developed in all wall thicknesses for which they are to be used.

STRUCTURAL BURNED-CLAY FLOOR, FIREPROOFING, PARTITION, AND FURRING TILE

Class	Absorption, per cent		Compressive strength based on net area, pounds per square inch			
			End construction		Side construction	
	Mean of five tests	Individual maximum	Mean of five tests	Individual minimum	Mean of five tests	Individual minimum
Hard	12 or less	15	4600 or more	3000	2400 or more	1700
Medium	16 or less	19	3200 or more	2250	1600 or more	1100
Soft	25 or less	28	2000 or more	1400	1200 or more	850

Where end-construction tiles are used on the side they shall meet the requirements of that construction, and vice versa.

Weights.—A tolerance of 5 % will be allowed on the following standard weights:

Structural Burned-clay Load-bearing Wall Tile

Size of unit, inches	Number of cells	Standard dry weight, pounds
3¾ × 12 × 12	3	20
6 × 12 × 12	6	30
8 × 12 × 12	6	36
10 × 12 × 12	6	42
12 × 12 × 12	6	48
12 × 12 × 12	9	52
3¾ × 5 × 12	1	9
8 × 5 × 12	2	16
8 × 5 × 12	3	16
8 × 5 × 12 (L shaped)	..	16
8 × 6¼ × 12 (T shaped)	4	16
7 × 7¾ × 12 (square)	6	24
8 × 10¼ × 12 (H shaped)	7	32
8 × 8 × 8 (cube)	9	18

Standard Partition Tile

Dimension, inches	Minimum number of cells	Standard dry weight, pounds
3 × 12 × 12	3	15
4 × 12 × 12	3	16
6 × 12 × 12	4	25
8 × 12 × 12	4	30
10 × 12 × 12	4	35
12 × 12 × 12	4	40

Flat Arch Floor Tile

Depth of arch, inches	Standard dry weight, per square foot of floor, pounds
6	26
7	29
8	32
9	35
10	38
12	42
15	50

Segmental Arch Floor Tile

Depth of arch, inches	Average dry weight per square foot of floor, pounds
6	30
8	36
10	40

Tile for Use in Combination Structural Clay Tile and Concrete Construction

Size of unit, inches	Minimum number of cells	Standard dry weight, pounds
4 × 12 × 12	3	16
6 × 12 × 12	4	25
8 × 12 × 12	4	30
10 × 12 × 12	4	35
12 × 12 × 12	4	40

Dimensions.—No dimension shall vary more than 3 % from the standard dimensions for any form of tile.

Weathering Resistance (Load-bearing Wall Tile).—All tile used in exterior work subjected to weathering conditions shall be able to withstand 100 alternate freezings and thawings. Tile classed as hard or medium by these specifications may be considered as meeting the weathering requirements, provided they are burned to the normal maturity for the given clay. Tile classed as soft shall be accepted as meeting the weathering requirement only on the basis of freezing tests.

Fire Resistance.—Load-bearing wall tile shall meet the following requirements as tested according to the Tentative Specifications for Fire Tests of Building Construction and Materials (serial designation C19 – 26T) of the American Society for Testing Materials as they apply for bearing walls and partitions and to be acceptable shall develop the following resistance periods as tested unplastered:

Thickness of wall, inches	Number of units in wall thickness	Number of cells in wall	Resistance period hours*
8	1	2	1½
8	1	3	2
12	1	3	3
12	2	3	4
12	2	4	5
16	2 or 3	4	8
16	2 or 3	6	10

* These are near the minimum values developed in tests. The average results will generally be higher. Plaster coatings ¾ in. thick applied on both sides and remaining in place throughout the fire test will increase the periods by 1 to 2 hours.

For floor tile and fireproofing, partition and furring tile, in cases where the fire resistance is an essential property, the purchaser shall specify the degree of fire resistance (fire-resistance period) required, and the manufacturer shall supply such available information on the fire-test performance of the given or closely similar product as will aid the purchaser in deciding whether the requirements are met. Further tests in accordance with the Tentative Specifications for Fire Tests of Building Construction and Materials (serial designation C19-26T) of the American Society for Testing Materials may be conducted by the purchaser.

Workmanship and Finish.—All tile shall be well burned and reasonably free from laminations and from such cracks, blisters, surface roughness, and other defects as would evidently interfere with the proper setting of the tile or impair the permanence of the construction.

The exterior surface of all tile intended for plaster or stucco shall be scored in such a manner as to give good adhesion.

Marking.—All tile shall bear the initials, name, or trademark of the manufacturer. Load-bearing tile shall also bear the word LOAD BEARING. Hollow tile intended for use in partitions shall also be marked PARTITION. These marks shall be indented on the exterior of the tile and shall be painly legible.

Inspection and Rejection.—Proper facilities shall be provided the purchaser for sampling and inspection either at the factory or at the site of the work, as may be specified in the contract. At least 10 days from the time of sampling shall be allowed for the completion of the test. The inspection shall be based on the requirements specified above. All tests shall be made in accordance with the methods hereinafter prescribed.

Individual tile shall be rejected for failure to meet the weight, size, or workmanship and finish requirements. In case of failure to meet the absorption and strength requirements for the class specified, the seller may sort the shipment, and new samples shall be selected by the purchaser from the retained lot and tested at the expense of the seller. In case the second set of samples fails to meet the test requirements, the entire lot shall be rejected.

Except as specified under Weights and unless otherwise agreed, the expense of inspection and testing shall be borne by the purchaser.

Tests and Testing.—Consult the A.S.T.M. specifications previously mentioned for standard tests and methods of testing.

40. Tests on Structural Clay Tile.—Since about 1920, many tests have been made by the United States Bureau of Standards (with the aid and coöperation of the Hollow Building Tile Association) to determine the strength and other physical properties of structural clay tile, structural clay tile masonry, and structural clay tile floors.

40a. Strength Tests on Load-bearing Structural Clay Tile Walls.—Strength tests of 70 structural clay tile walls constructed with ordinary workmanship and built under average indoor conditions were made.

The walls tested were all 6 ft. long and 9 ft. high and either 8 or 12 in. thick. In their construction, 14 different lots of tile and four different mortar mixtures were used. Before being tested in compression under central loading, 27 of the walls were subjected to a transverse test; 53 of the walls were tested in compression under central loading, and 17 under eccentric loading.

COMPRESSION STRENGTH OF STRUCTURAL CLAY TILE WALLS

Mortar	Number of walls	Construction	
		End	Side
		Compressive gross area, pounds	Strength, pounds per square inch
Lime ($1\frac{1}{4}L:3S$)	4	90 90	160–170
Cement lime ($1C:1\frac{1}{4}L:6S$)	15	240 430	240–480
Cement lime ($1C:1\frac{1}{4}L:4S$)	29	440 690	220–510
Cement ($1C:3S$)	4	340 370	350–370

The mortar and workmanship seemed to be the most important factors affecting the strength of the walls.

There seemed to be no constant ratio between the strength of the walls and the strength of the tiles, but, in general, using the same mortar, this ratio decreased with an increase in tile strength.

With the eccentrically loaded walls, the maximum loads supported were about 60 % of the loads for similar walls centrally loaded.

The transverse strength of the walls was largely affected by differences in mortar and in the position of the tiles. In general, the stronger mortars gave higher transverse strength, and the wall having the tiles laid on the side were stronger under side load than with the tiles on end. The results of the transverse tests show that the 8-in. walls resisted side pressures equivalent to 30 to 115 lb. per ft.^{2}, and the 12 in. walls, side pressure of 120 to 150 lb. per ft.^{2}

The average strengths of each set of side-construction walls built of tiles having a compressive strength of more than 500 lb. per in.^{2} and with $1C:1\frac{1}{4}L:4S$ mortar were, in all cases, greater than 330 lb. per in.^{2} The average for end-construction tile walls was greater than 450 lb. per in.^{2}

The end-construction walls were stronger than the side-construction walls only when built with rich mortar and with the central longitudinal webs of the tiles in bearing.

The average net area compressive stress of the 107 individual tile tested, including 29 tile which would grade as soft and partition tile, amounted to 4000 lb. per sq. in. net area of tile section. The average net area compressive strength of all the medium and hard side- and end-construction tile tested amounted to 4500 lb. per sq.in. Some of the tile tested 8510 lb. per sq. in. Other structural clay tile has tested over 12,000 lb. per sq. in.

40b. Tests of Structural Clay Tile and Concrete Slabs Reinforced in One Direction.—The following discussion is taken from Technologic Paper No. 291, of the Bureau of Standards.

Beams, which represented sections of typical combination structural clay tile and concrete floor slabs reinforced in one direction, were made and tested in the laboratory for the purpose of obtaining information on the value of hollow tiles in resisting bending and shearing stresses. The test pieces consisted of 42 beams from 8 ft. 10 in. to 15 ft. 3 in. long, all 8 in. in depth and having a maximum width of 30 in. For the purpose of comparison, two concrete beams having the same sectional area as the gross sectional area of the composite beams and three concrete beams having the same sectional area as the concrete ribs in the composite beams were also tested.

Observations were made of the deformation in the concrete, tiles, and reinforcement, deflection of the center of the beam, and development of cracks as the loads are applied.

The results of these tests seem to warrant the following conclusions:

For Beams without Topping.—1. In resisting bending stresses each hollow tile and concrete rib in the combination beams was equivalent in strength to a rectangular concrete beam having a width at least equal to the width of the concrete rib plus $1.3\ (s + w)\ \frac{E_t}{E_c}$ where

E_c is taken as 2,000,000 lb. per in.^{2} and
s = thickness of one vertical tile shell, inches
w = thickness of one vertical tile web, inches, and
E_t = modulus of elasticity of the tiles, lb. per in.^{2}

2. The average strength of the beams having mortar in the cross-joints between the tiles was only slightly greater than the average strength of the corresponding beams having open joints.

3. The effect of the tiles at loads less than the maximum upon the deformations in the concrete, the position of the neutral axis, and the deflections was apparently equal to or greater than the effect of adding a width of concrete to each concrete rib equal to $2(s + w)\ \frac{E_t}{E_c}$.

4. The compressive stresses in the shells of the hard tiles in contact with the concrete ribs were greater than the compressive stresses in the adjacent concrete.

For Beams with a Topping. The top shells of the tiles in contact with the concrete seemed to be as effective in resisting compressive stresses as an equal area of concrete in the same location.

For Both Types of Beams.—1. On the assumption that the shearing resistance of the concrete in the combination beams was equal to its resistance in the concrete beams which failed by diagonal tension, the assistance of the two rows of half tile adjacent to each concrete rib was at least equivalent to the following widths of concrete in resisting shearing stress: Tile of lot 1, 2.2 in.; tile of lot 2 with mortar joints, 1.9 in.; tile of lot 3, 3.4 in.; tile of lot 3 with mortar joints, 2.5 in.; tile of lot 4, 2.4 in.

2. The combination beams containing bent-up bars for web reinforcement resisted an average shearing stress over the $b'jd$ section of 511 lb. per in.² without visible indications of diagonal tension failures. (These bent-up bars were provided with special anchorage by means of hooks in the solid concrete sections beyond the supports.)

3. The strength of the bond between the concrete and tiles even with open joints was sufficient to permit failures of the beams by compression and diagonal tension. These seemed to be no failures caused primarily by the failure of this bond.

40c. Fire Tests.—Since 1920, several series of fire tests, with compression and other auxiliary tests of individual tile, have been completed by the U. S. Bureau of Standards with the cooperation of the Hollow Building Tile Association.

The final results and conclusions from these tests have been prepared for publication as a paper in the Bureau of Standards Technologic series.

FIRE-RESISTANCE PERIODS OF WALLS OF LOAD-BEARING STRUCTURAL CLAY TILE WHEN THE RESISTANCE PERIOD IS LIMITED BY THE TEMPERATURE RISE OF THE UNEXPOSED SIDE OF THE WALL

Thickness of wall, inches	Number of units in wall, thickness	Number of cells in wall, thickness	Fire-resistance period, hours	
			Unplastered	Plastered, both sides
8	1	2	1½	2½
8	1	3	2	3
8 (brick faced and plastered on fire side only)	2	1	....	4½
8 (furred one side)	2	2 or 3	....	5
12	1	3	3	4
12	2	3	4	5
12	2	4	5	7
12 (brick faced and plastered on fire side only)	2	2	....	6
16	2 or 3	4	8	10
16	2 or 3	6	10	12

As shown in the preceding table, when the temperature rise on the unexposed side of the wall governs the fire-resistance period of the wall, this period is dependent on the wall thickness, number of cells, or shells, and use or non-use of plaster. In addition, the type of construction, the design of the units, and the workmanship are also important factors.

Briefly summarizing, it can be said with reasonable certainty that standard-weight tile, properly made from suitable clay, will ensure tile walls capable of giving the fire-resistance periods indicated. On this basis, walls 8 in. thick will probably be adequate in residence, office, or institutional occupancies where no considerable accumulation of combustible material is present. The fact that for fire-resistive interior construction 12 in. is the general minimum wall thickness used gives an added factor of safety. For mercantile or manufacturing occupancies with moderate amounts of combustible materials, the 12-in wall will apparently be adequate. For heavier manufacturing warehouse or storage occupancies, walls heavier than 12 in. may be needed, particularly if not plastered. Sixteen-inch unplastered walls give fire-resistance periods of from 8 to 10 hr., and, if plastered, 10 to 12 hr.

It is therefore shown by these tests that hollow tile walls in practical thicknesses will provide a full range of protection under all conditions usually encountered in connection with fires and buildings.

40d. Absorption, Freezing and Thawing Tests.—Results of tests made on many varieties of tile and results of investigations made on structural clay tile buildings indicate that structural clay tile which is acceptable for different uses according to the A.S.T.M. Standards and Tentative Standards will prove satisfactory for the respective construction purposes. See Art. 39 for specification requirements.

40e. Adhesion Tests.—Adhesion tests have been made on medium structural clay tile, using gypsum plaster for experimental purposes. Scratched scoring gave best results. Grooved scoring gave poorest results. Tests show that structural clay tile provides a very strong base for gypsum plaster. Plaster-adhesion tests on smooth tile gave a minimum of 1 lb. per sq. in. Cement and cement-lime plaster tests have been made upon structural clay tile, and excellent results have been obtained.

40f. Ordinary Temperature Tests.—The incomplete results of ordinary temperature tests on structural clay tile and other fireproof building materials discloses the fact that structural clay tile is a good insulator against the passage of heat compared to concrete, brick, and stone. This is mainly due to the sealed air cells in the structural clay tile walls.

40g. Sound Tests.—Tests on transmission of sound through various building materials are being conducted by the Bureau of Standards. Of the fire-resisting building materials, structural clay tile with gypsum plaster provides one of the best sound-insulating materials.

41. Minimum Requirements for Masonry Structural Clay Tile Wall Construction.—Recommended Minimum Requirements for Masonry Wall Construction, by the Bureau of Standards, specifies that:

Structural clay tile used for exterior bearing walls or piers or for party walls shall be of quality at least equal to the "Medium Class" as prescribed by Specifications for Hollow Burned-clay Load-bearing Wall Tile of the American Society for Testing Materials.

When used for non-bearing purposes and not exposed to the weather, structural clay tile may be of a quality not inferior in any respects to the "Soft Class" described in the above specifications.

Walls of structural clay tile shall be supported at right angles to the wall face at intervals not exceeding sixteen times the wall thickness in top stories, or eighteen times the wall thickness elsewhere. Such lateral supports may be in the form of cross walls, piers or buttresses when the limiting distance is horizontal, or floors when the limiting distance is vertical. All such walls, piers, etc., shall be properly bonded and of sufficient strength to withstand all wind forces acting upon them.

The maximum allowable compressive stresses in masonry of structural clay tile due to combined live and dead loads shall not exceed 80 lb. per sq. in. of gross sectional area, when laid in Portland cement mortar, and 70 lb. per sq. in. of gross sectional area when laid with special cement lime mortar.

Walls of hollow tile shall not exceed 50 feet in height above the top of foundation walls.

The minimum thickness of exterior walls of structural clay tile construction shall be 12 in. for the uppermost 35 feet of their height and at least 16 in. for the remaining lower portion; except that the top story wall of a building not exceeding three stories or 40 ft. in height, or the wall of a one story commercial or industrial building may be 8 in. thick, provided that the roof beams are horizontal; and except that exterior walls of one and two family dwellings may be 8 in. thick for the uppermost 20 ft.

When gable construction is used for such dwellings an additional 5 ft. is permitted to the peak of the gable.

When face brick is backed up with structural clay tile and bonded at least every sixth brick course with header brick the full cross section of the wall may be considered in computing bearing strength.

Fire walls of structural clay tile shall be not less than 16 in. thick in any part, except that for residential buildings they may be not less than 12 in. thick throughout.

Fire division walls of structural clay tile shall be not less than 12 in. thick in any part, and for buildings of storage and heavy manufacturing occupancy they shall be not less than 16 in. thick throughout.

Non-bearing partitions of structural clay tile shall be built solidly against the floor and ceiling construction below and above and shall not exceed the following unsupported heights:

Partition thickness, inches	2	3	4	6	8
Partition height, feet	8	12	15	20	25

Foundation walls of structural clay tile shall be not less than 12 in. thick.

Panel and inclosure walls in buildings of skeleton construction shall be not less than 8 in. thick if of structural clay tile.

CAST IRON

By James H. Herron

42. Kinds of Cast Iron.—Cast iron may be considered of several classes, depending upon the compositon and method of manufacture. Falling within the general term, there is the so-called *gray cast iron, semi steel* and *white cast iron;* the latter is subsequently treated to produce the so-called *malleable iron.* While the term cast iron is not usually applied to the white and malleable irons, it rightfully should be under the general definition of this material.

43. Methods of Manufacture.—Cast iron has its source in the blast furnace where the ore is reduced to the metallic iron and cast into pigs, commonly known as *pig iron*. This metallic iron carries with it certain elements which have a marked effect upon the physical properties of the material—such elements as carbon and sulphur which the iron picks up from the coke with which the ore is smelted; silicon which is picked up from the silica present in the ore and ash of the coke; and manganese and phosphorous which are present in the ore. All of the above elements have some effect upon the physical properties of the material, therefore the foundryman is compelled to use discrimination in selecting his materials in order to get the properties desired. In view of this it is unwise for the engineer to specify the chemical properties of the cast iron. He should limit himself to the physical properties, permitting the founder to supply what best meets the physical need.

Cast iron may be poured direct from the blast furnace or remelted from pig by any one of the following methods: cupola furnace; air furnace; electric furnace; open hearth furnace. Only foundries making a large tonnage of casting and located adjacent to a blast furnace, can satisfactorly use the direct method; consequently, as a rule one of the other methods will be in use. The cupola furnace, using iron scrap and pig, is common in making gray iron castings and also to some extent in making small white and malleable iron casting. The air furnace is used to a limited extent only in making iron casting but is generally used in making white and malleable iron castings. The electric furnace is used in making both gray and white (and malleable) iron castings, while the open hearth furnace is used only in making white and malleable castings where the tonnage is large.

Very little iron for construction purposes will be melted by any other method than in the cupola furnace, and while the air and electric furnaces produce better products, the cost is higher and they are therefore not in common use.

44. Gray Iron.—Gray iron castings made from gray iron, are usually known to the trade as "cast iron." Gray iron is defined by the International Association for Testing Materials as "Iron containing so much carbon that it is not usefully malleable at any temperature, and is restricted to cast iron in the form of castings." Gray cast iron, or properly speaking, gray iron castings are produced as above stated, using metal directly from the blast furnace or pig iron, the produce of the blast furnace, and scrap melted in the cupola, air or electric furnace.

Gray cast iron always contains an important percentage of carbon, ranging from 3 to 4%, and an important percentage of silicon. The carbon present in gray iron is in two forms, called graphitic carbon and combined carbon, and the material is hard or soft depending upon the proportion of these two forms of carbon. In other words, the castings are hard when the combined form of a carbide of iron and adds to the strength and hardness of the material. The graphitic carbon is graphite in the form of thin flakes, leaving a net work or regular skeleton of the alloy surrounding it.

In general gray iron may be considered a mass consisting of particles of graphite surrounded by a matrix of metallic alloy. The strength of iron is greatly affected by the condition of the carbon. The crystals of the graphite are brittle and show decided cleavages, hence they cannot be a factor in the strength of the iron. Thus by breaking up the continuity of the matrix the graphite causes weakness which will vary directly with the quantity.

The silicon plays an important part in the physical properties of gray iron, not directly, but in its effect on the condition of the carbon. The higher the silicon, the greater the amount of graphitic carbon, hence the less the amount of the combined carbon, and the softer the iron. The foundryman therefore regulates the physical properties of his material in regulating the amount of silicon by the proper mixing of his different irons.

Sulphur has the opposite effect of silicon and tends to harden the iron by increasing the combined carbon. Thus, sulphur is to be avoided in soft irons and only plays an important part in the so-called chilled irons, as in car wheels and like products where the surface is rendered hard.

Manganese tends to harden the iron and to offset the effect of the sulphur. It is sometimes referred to as a veil for the sulphur so that when high sulphur iron only is available some increase in the manganese will offset the difficulty to be expected with high sulphur.

Phosphorous in cast iron is not detrimental in percentages varying from 0.30 to 0.50 %. Where great fluidity is required, the amount may be as high as 1.00 %.

The above discussion of the effect of the chemical constituents upon the physical properties of gray iron is not given with a view of encouraging the engineer to write his own chemical specifications for what he thinks desirable, but to endeavor to show him the futility of such effort. The chemical constituents of gray iron should be determined by the foundry metallurgist and the engineer should only specify the physical properties he desires.

The physical properties of gray iron vary between somewhat wide limits depending upon the size and dimensions of the casting. The American Society for Testing Materials publishes a flexible specification (see A.S.T.M.

Specification for Gray Iron Castings, A48-18) which gives the physical properties to be expected in different casting thicknesses. The specification is perfectly rational and can be met by any foundryman without imposing upon him an undue burden. It is therefore wise to follow these specifications, care being taken that the one of the latest revision be used. These specifications are changed from time to time as the art improves.

Gray iron possesses comparatively little strength in tension and no ductility. This therefore renders the use of gray iron castings in tension uncertain and they should not be so used unless the load is static and unit stress is low. Gray iron possesses its greatest value in compression where the ultimate strength is about four times that in tension. For construction purposes it is therefore wise to consider gray iron only in compression. It should be used for column bases, floor plates, columns under some conditions, etc.

45. Semi-steel.—Semi-steel, so called, is subject to the same discussion as in the case of gray iron, and is made by adding steel scrap to gray iron mixtures in the melting furnace.

Semi-steel is supposed to be stronger than gray iron but unless care is taken and the foundryman thoroughly understands the manufacture of semi-steel, there is great question whether there are any beneficial results. The usual additions of steel scrap vary from 10 to 25%, and the strength increases with added amounts up to about 30%, above which the strength tends to fall off. Semi-steel may be used where greater strength is desired than can be realized from gray iron and the same character of applied stress should govern. Semi-steel is more properly known as high-strength gray iron and is so designated by the American Society for Testing Materials under serial No. A-88-24. In this specification the minimum strength specified is 28,000 lb. per sq. in. in tension.

46. White Iron.—White cast iron is used only in cases where a chilled surface is required to resist abrasion, but when there is no tensile stress or shock. In white iron the carbon is all in the combined form, therefore it cannot be machined except by grinding. Inserts of white iron ore are sometimes used when there is sliding contact.

47. Malleable Cast Iron.—Malleable cast iron, which is commercially known as malleable iron, is defined by the International Association for Testing Materials as "Iron which is first cast iron and later made malleable without remelting." Malleable cast iron is first cast in white iron using the air, cupola, electric or open hearth furnace. Small castings are frequently produced by cupola melting but the majority of all castings are produced in the air furnace. After casting as white iron (all of the carbon in the combined form), the castings are inspected, after which they are packed in boxes with an oxidizing agent, in which they are heated for a period of from 5 to 7 days. In this treatment known as annealing, the combined carbon is changed to the form of graphite, known as *temper carbon*. At the same time the outside surface is decarbonized by the action of the oxidizing agent. The form of the graphitic carbon varies from that of gray iron inasmuch as the gray iron is in the form of flakes and therefore occupies the greater part of the cross sectional area, while in malleable iron it is in the form of nodules occupying a lesser amount of the cross sectional area, leaving a greater percentage of the matrix effective. Since the carbon is practically all graphitic, the matrix is soft and ductile.

The use of malleable iron is constantly growing and at some future day will find an extended use in construction work. It is now used principally for hardware, concrete inserts, hanger straps, etc. It can be used in tension to some extent and for transverse loading. In compression malleable iron has no advantage over gray iron and is more expensive.

Malleable cast iron in tension has a value from 40,000 to 50,000 lb. per sq. in. and an elongation of from 7 to 15%.

Specifications for malleable iron of the American Society for Testing Materials should be used when malleable castings are desired.

48. Design of Castings.—Care should be taken in the design of castings for whatever purposes intended, and sharp corners and angles should be avoided, using well rounded corners and large fillets. This is desirable owing to the fact that in all metals, upon solidifying, the crystals grow at right angles to the surface. This causes weakness along a line bisecting the angle of the surfaces, along which failures may occur.

The section of ribs, etc. should be kept as nearly uniform as possible. A large section immediately adjacent to a light section is apt to cause difficulty and internal troubles. The engineer should exercise great care and judgment in the design of castings for any purpose whatever, since a little judgment shown at such a time will avoid failure which might be destructive to both life and property.

The defects in castings of all kinds are: (1) blow holes which occur near the surface and are usually indicated by surface porosity; (2) contraction cavities which are usually found below the surface at the intersection of large and small sections (usually referred to by the foundrymen as shrink holes); and (3) scabs, which are purely surface defects, and as a rule cause no trouble except where it is desired to make connection with some other member without machining.

WROUGHT IRON

BY JAMES H. HERRON

49. Wrought Iron Defined.—Wrought iron is defined by the International Association for Testing Materials as "Malleable iron which is aggregated from pasty particles without subsequent fusion and contains so little carbon that it does not harden usefully when cooled rapidly."

50. Method of Manufacture.—Wrought iron is manufactured by the process of puddling, —*i.e.*, melting in a furnace from pig iron and ore and constantly stirred until practically all the carbon and other impurities are burned out. This leaves the iron in a plastic condition, saturated with slag. The material is gathered into a plastic lump and put in a "squeezer" where much of the slag is squeezed out. The remaining material is then rolled into billets known as "Muck Bars." Subsequent rollings refine the material by further eliminating the slag and it is called single and double refined iron, depending upon the number of times rolled.

51. Structure of Wrought Iron.—The structure of wrought iron is commonly called fibrous due to the presence of a considerable amount of slag. This slag is found in alternate layers with the iron, which gives the appearance of fibers and which is referred to at times as "woody." The layers of slag serve as a protecting covering for the alternate layers of iron, thereby rendering the material somewhat immune to corrosive conditions. The carbon content is usually under 0.15%, with the manganese under 0.30%.

52. Physical Properties.—The physical properties of wrought iron are fairly constant; the tensile strength from 50,000 to 60,000 lb. per sq. in., with the elastic limit from one-half to three-fifths of the tensile strength. The elongation is high denoting good fatigue-resisting properties, but the reduction of area is usually low owing to the high slag content.

53. Uses of Wrought Iron.—The greatest value of wrought iron is in its ability to resist corrosion and is in consequence used for sheets, both plain and corrugated, metal lath, pipe, etc. Practically no wrought iron is now used for structural shapes. Probably the most important use of wrought iron is in pipe where its resistance to corrosion results in long life and good service. Wrought iron can be identified by the surface appearance of small hairline checks which represent the slag.

Wrought iron should be purchased under the specifications of the American Society for Testing Materials.

54. Ingot Iron and Copper Bearing Metal.—In the same general class with wrought iron in its resistance to corrosion, are the so-called ingot iron and copper bearing metal.

Ingot iron is made in the open hearth furnace, eliminating as far as possible the impurities usually found in steel, thereby obtaining as pure a product as possible. It is then cast in ingots and rolled into the form required. Owing to certain properties of this material it is hard to handle in forging operation, therefore any forgings required should be carefully made.

The value of this material lies largely in its capacity to resist corrosion due to the low percentage of impurities, and it is furnished in sheets both black and galvanized. There are no specifications under which this material is furnished. It is usually supplied under various trade names.

Copper bearing steel takes its name from a small percentage of copper, from 0.30 to 0.50 %. This contributes to its capacity to resist corrosion, probably by alloying with the iron. The other constituents are as low as is practical. This material is used for sheets for sheathing, metal lath, etc.

STEEL

BY JAMES H. HERRON

55. In General.—Chemically, steel may be defined as an alloy of iron-carbon and other elements being present in varying amounts depending upon the properties desired. Where the steel is composed of an alloy of iron and carbon with other elements in small quantities, it is customary to refer to such material as carbon steel. Where small quantities of other elements

(such as nickel, chromium, vanadium, etc.) are present in addition to the iron and carbon, it is customary to refer to the material as alloy steel.

Of the elements entering into the composition of steel, some are of value, while others are a detriment. The value of the steel is determined largely by these elements. Not only should their presence be considered, but the amount of each should be accurately determined. They will be taken up in the order in which they are usually regarded.

Carbon.—The general influence of carbon on steel is greater tenacity. It also renders the steel harder and stiffer. The tensile strength is increased about 600 to 800 lb. per sq in. for each additional point of carbon, while the ductility is decreased about 0.5 % for each additional point of carbon (see Fig. 1). Steel with 0.20 % carbon begins to show appreciable hardening when cooled quickly, but does not show evidence of brittleness in the normal state, until the carbon has reached approximately 0.70 %.

Manganese.- Manganese adds to the toughness of steel and increases the tensile strength by about 100 lb. per sq. in. for each additional point. The ductility is decreased with the addition of manganese. For medium steel the manganese is very satisfactory at from 0.10 to 0.60 %. Higher or lower manganese may be specified for special purposes. Steel with manganese between 2 and 6 % should be avoided, due to increased hardness and a tendency to brittleness, while steel of over 6 % manganese, known as *manganese steel*, has certain definite properties of toughness and strength.

Phosphorus.—Phosphorus renders steel cold short, or brittle. It is therefore to be avoided as much as possible. The lower the phosphorus content, the better. Steel should be specified with phosphorus not to exceed 0.01 %.

Sulphur.—Sulphur has a tendency to render the steel hot short, and is therefore to be avoided in any steel that is to be forged, or otherwise worked hot. The sulphur, for good results, should not exceed 0.06 %. It is much better to keep the sulphur below 0.04 %.

Silicon.—Silicon is usually supposed to render steel brittle. High silicon should be avoided in steel for general purposes and should not exceed 0.20 % except in castings or alloy steels.

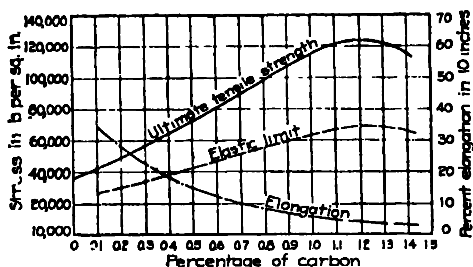


FIG. 1.—Effect of carbon upon the strength and ductility of carbon steel.

Nickel.—Nickel in steel has a strengthening effect or tends to increase the value statically over the range above considered and in proportion to the amount present. Where the nickel content is 3.50 % (much of such steel is used) and in the annealed condition, its presence tends to increase the elastic limit from 25 to 50 %, depending upon the amount of carbon present.

Chromium.—Chromium in steel tends to make it intensely hard and give it a high elastic limit in the hardened or suddenly cooled state so that it is neither deformed permanently nor cracked by extremely violent shocks. It is stated that the hardness imparted by chromium in steel is not accompanied by as much brittleness as that induced by carbon.

56. Methods of Manufacture.—Steel is manufactured by one of several methods of which the following are important:

Bessemer.—Bessemer steel takes its form from the inventor of the process by which it is made. The process was patented by Sir Henry Bessemer in 1855, and due to the low cost of manufacture, has contributed to the popularity of steel perhaps more than any other one factor. The converter which is used is a pot shaped vessel receiving the iron in the molten form, either direct from the blast furnace or from a cupola. Air is blown through the molten mass, thereby oxidizing the silicon, carbon and manganese. The heat of the reaction maintains the metal in a fluid condition until conversion is complete. Owing to the inability of this method to materially reduce the phosphorus or sulphur, two harmful elements, and loss due to some oxidation of the iron itself, it is rapidly being replaced by other methods which are more flexible. Bessemer steel may be identified by the high sulphur and phosphorus content.

Open Hearth.—Open hearth steel takes its name from the character of the furnace in which it is manufactured. This is a furnace of the regenerative type originally introduced by Sir William Siemens. The metal is melted on the hearth of the furnace, the hot gases passing over the surface, the heat being absorbed through the top of the bath. By a proper use of slags, phosphorus and sulphur can be reduced to any reasonable extent Other conditions can be controlled at will. This method is therefore much in favor and the bulk of the steel for structural material is now made by this process.

Electric.—Some steel is now made in the electric furnace and is known as *electric steel*. The steel is melted from cold materials and as such is known as *cold melt electric;* in connection with the open hearth is known as *duplex electric;* or with the Bessemer and open hearth is known as *triplex electric*. Electric steel is largely alloy steel and has little use in building construction unless a high strength is required.

57. Carbon Steel.—Carbon steel is defined by the International Association for Testing Materials as "steel which owes its distinctive properties chiefly to the carbon as distinguished

from the other elements which it contains." It also can be defined as an alloy of iron, and carbon varying from 0.10 to 2.25%.

A large part of the steel used for building construction is of this class and may be classified as soft, medium, and hard. Soft steel is that with a carbon content of 0.25% or under, medium steel is that of a carbon content from 0.25 to 0.50%; and hard steel is that with a carbon content exceeding 0.50%. Little steel with a carbon content exceeding 0.70% is used in building construction since steels in the higher range of carbon are known as brittle and would have little use in an untreated condition. Springs and steels for metal and wood working tools fall in this class.

Since the greater part of the steel used for building construction is carbon steel, the character of each kind should be carefully considered for different purposes.

Bessemer steel is used for little except rails, structural steel for buildings and concrete reinforcement bars, and much discrimination should be shown in regard to whether it should be used for any of these purposes. The high phosphorus present renders its use inadvisable when there is a condition of dynamic loading, so that in structures subject to heavy live load conditions, it should not be considered. The specifications of the American Society for Testing Materials provide for structural steel for buildings[1] for both Bessemer and open hearth steel. The engineer should therefore be careful in making his selection to meet the need.

The use of open hearth steel should be encouraged. Its use is constantly increasing and the prediction is freely made that in the course of a few years it will entirely replace Bessemer steel except for a few specialized uses. By far the greater part of the specifications of the American Society for Testing Materials as now written call for open hearth steel.

58. Alloy Steel.—Alloy steel is defined by the International Association for Testing Materials as "steel which owes its distinctive properties chiefly to some element or elements other than carbon or jointly to such other element and carbon."

The simplest class of alloy steel is that having one alloying element in addition to iron and carbon. The best known of these steels are nickel steel, chromium steel, manganese steel, and silicon steel.

Nickel steel has the most extensive use of all alloy steels for any purpose whatever. It is the general prediction that ultimately nickel structural steel will be used in practically all important structures. The strength of nickel steel is about 25 % higher than carbon steel for the same elongation and for the same purpose. Some use has already been made of nickel steel for structures and should be considered where physical conditions may limit the size of the members. Nickel steel is used in the normal (rolled) condition. The properties are considerably improved by heating treatment.

Chromium steel is used when extreme hardness is required. For such members as bearing plates that must resist crushing or wear or similar service, this material can be satisfactorily used. Chromium steel can be machined when annealed, but must be treated to be effective in use.

Manganese steel is a casting alloy possessing great resistance to abrasion and is used when a casting will apply. It cannot be finished except by grinding so cannot be used where other machining is necessary. It has found a use for switches and frog points, steam shovel bucket points and the lips of grab buckets. Its use is growing and the future will see a greatly extended use of this material.

Silicon structural steel has been used in some recent important structures. This steel is higher in carbon and manganese than carbon structural steel; therefore, some of the additional strength would come from these elements. The usual specification allows carbon as high as 0.40 % while the silicon is not under 0.20 %. The physical properties should be

Tensile strength, pounds per sq. in. 80,000	95,000
Yield point, pounds per sq. in.	45,000
Elongation in 8 in. minimum, per cent	1,500,000 / Tensile strength

The hardness is greater than carbon structural steel; therefore, some difficulty may be experienced in shearing and punching for fabrication. Complete examination should be made for incipient cracks normal to the line of cutting. In important connections such cracks should be machined off or holes reamed out. There is some thought that the higher properties of silicon structural steel are primarily due to the higher carbon and manganese rather than the higher silicon content.

The American Society for Testing Materials has a proposed tentative specification for silicon structural steel under serial designation A-25T.

The more highly developed alloy steels of the quarternary group have little application to building construction. Among these steels are the *chrome-nickel*, *chrome-vanadium*, *silico-manganese* and others carrying *tungsten*, *molybdenum* and *cobalt*. Consideration of these steels with their properties as affected by treatment, would be beyond the scope of this work.

[1] See Appendix *C*.

If the reader feels sufficiently interested in the subject, it would be well to procure some well known book on the subject, and study the same carefully, if to promote nothing more than an appreciation of this exceedingly important and far reaching subject.

59. Steel Castings.—For building construction, practically all steel castings are of carbon steel. This is usually of the medium grade (0.25 to 0.50%) along the lower carbon range. While steel castings may be used in tension, such use is fraught with some danger and it is safe to consider such for compression or transverse loading only—the latter when the probability of contraction cavities will occur near the neutral axis or on the compression side.

The specifications of the American Society for Testing Materials should be used when steel castings are to be used.

The same imperfections that are found in iron castings are common to steel castings but in a more pronounced degree.

60. Rolled Shapes.—Rolled shapes—viz., beams, channels, angles, plates and bars—comprise the large part of steel used in building construction. This in a great measure is carbon steel of the soft and medium grades. The handbooks of the various steel manufacturers give full tables of the properties of the various sections rolled, also table of safe loads for different classes of loading. These tables use a factor of four, or a unit stress of 16,000 lb. The American Institute of Steel Construction recommends a stress of 18,000 lb. per sq. in. The discriminating designer will consider the elastic limit rather than the ultimate strength and select an allowable unit stress that will be sufficient to cover the needs. It is manifestly necessary to allow a less unit stress where the conditions of loading are dynamic than where static. The specifications of the American Society for Testing Materials for structural steel should be used (see Appendix C).

61. Forgings.—When rolled shapes are not available forgings can be made to suit the need and should be annealed before used to relieve the strain set up in the hammering operation. The specifications of the American Society for Testing Materials for forgings and annealing should be used.

62. Uniform Specifications.—Uniform specifications have been realized in recent years through the efforts of the American Society for Testing Materials. The specifications of this Society should be used in every case where they apply. Time will be saved in drawing up general specifications by using the name, serial designation and latest revision of the particular specifications.

63. Examination of Structural Steel.—In the examination of structural steel, the following flaws should be guarded against:

Pipes in structural steel appear as a small split, crack or fissure in the sheared or sawed end of the section. On sheared heavy sections the dragging may tend to hide it, but the practiced eye will detect the lip. In most sections the pipe in itself is not a dangerous defect as it is found in the center of the web, where the stresses are small or neutral, but presence of pipe indicates insufficient discard from the top of the ingot. This means that segregated poor material is very apt to be present.

Scabs need very little description and are easily detected. They are not a dangerous defect but often interfere with fabrication and prevent the workmanlike finish desired. Scabs are the result of splashes on the side of the mold during the process of pouring.

Rooks are often mistaken for scabs as they draw out in the process of rolling. They are the result of transverse cracks formed by too heavy reduction in the early stages of rolling. They may be very deep and dangerous so should be carefully discarded.

Laps formed by rolling, an over-fill from the previous pass, are not generally dangerous unless they are unusually deep. Seams result from the drawing out of surface blow holes or other minor defects. They are not dangerous where the material is not to be forged or heat treated, but they, like laps, are unsightly and prevent workmanlike finish.

Guide marks and roll scratches are often taken for laps or seams. A bending test or pickling will generally reveal the true nature of such a defect.

64. Steel Lumber or Structural Pressed Steel.—Steel lumber is a term applied to pressed steel beams and channels designed to take the place of wood joists and studs in building construction. The word *steel lumber* is more or less of a trade name since practically the same material is made under the general term of *structural pressed steel.*

Structural pressed steel is formed from rolled sheets into channel sections with the outside edge of the flange turned toward the inside and parallel to the web (see Figs. 2 and 2A). The

value of this form is to stiffen the outside of the flange on the compression side. The web and flanges are uniform in thickness and structure, having been rolled as a sheet. To produce a beam, two channel sections are placed back to back and either riveted or spot welded, thus having twice the carrying capacity of the channel and something over twice the lateral stiffness. The transverse strength is less per unit of weight than in a standard beam of the same depth since the flanges are thin in proportion to the web.

The superiority of structural pressed steel is supposed to lie in its ability to lighten the construction over the regular standard rolled section and at the same time possesses the fire proof features lacking in wood members.

Structural pressed steel is made in sections up to 12 in. in depth, the thickness of the sheet from which they are made being proportional to the size of the member. Special shapes can be made at little additional cost.

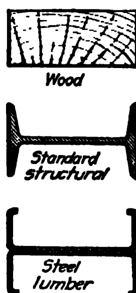


Fig. 2.—Cross section of structural pressed steel beam compared with standard structural and wood.

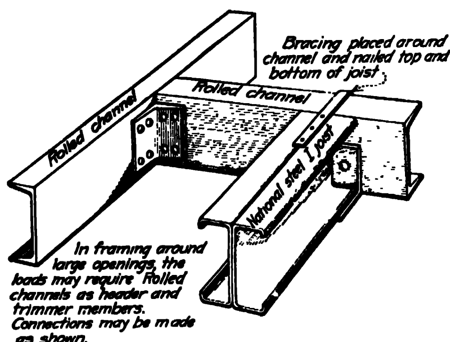


Fig. 2.1.—Method of fra ing structural pressed steel.

In using this material in design, the same general rules apply as in the case of standard structural shapes. Tables of properties and safe loads are furnished by the manufacturers. Structural pressed steel can be used in connection with standard structural shapes, connecting with hangers, angles, or supported on top of them and held with a clip. This renders the application in the field a simple matter. The pressed sections may be built into the wall, or into a reinforced concrete girders.

The studding is in channel form and can be applied either on the top of the floor using a channel or angle base or track, or on the joists directly, with the joists above carried upon the studs.

The metal lath used for floor reinforcement, ceiling or side wall construction is clipped to the pressed steel members. The prongs for clipping are cut from the flanges of the joists or studs.

The ease of making the connections in structural pressed steel with little field work commends its use where great strength is not required. It probably can be erected at little greater cost than wood, joists and studs. Each particular application should be studied to avoid trouble.

The introduction of structural pressed steel has raised some questions which might be stated briefly as follows: (1) The use of a thin floor which shows a tendency to crack where the joists are long span, due to both defection of joists and slab; (2) thin plastered covering of wall and ceiling, possibly too thin to protect members from effect of heat in case of fire; (3) Thin section of members, offering little resistance to corrosion under damp or corrosive conditions.

METAL LUMBER

By A. W. Piltz

65. Types of Metal Lumber.- Metal lumber, as described in this article, may be classified as follows:

1. Steel joists:
   - Open-type truss.
   - Plate-girder joists.
   - I-beam joists.
   - Channel joists.
2. Steel studs.
3. Steel roof deck.

This does not by any means cover the entire field of metal lumber. Metal lath, forms, beams, girders, columns, etc., are described in other portions of this book.

Metal lumber, as described here, consists of light-weight metal sections used to support the floors, roof, walls, and partitions of fireproof or fire-resistant buildings. The sections are light weight, convenient to handle, and can be obtained from the manufacturer fabricated and ready for the job. They are easily and rapidly erected under almost any weather conditions.

Further information on the different sections described below can be obtained from the technical publications of the different manufacturers.

66. Steel Joists.

OPEN-TYPE TRUSS

The Macomber Steel Company, Canton, Ohio, makes the "Massillon" bar joist in the shape of the Warren truss. The main members consist of round bars of structural-grade steel, and, at the ends, vertical and horizontal plates are used for bracing, bearing, and gusset plates. All the connections are welded. The joists are made in five depths—8, 10, 12, 14, and 16 in.—and cover a range of spans from 4 ft 0 in. to 31 ft. 0 in.

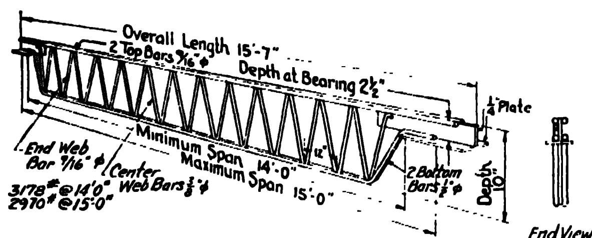


Fig. 3.—Massillon bar joist.

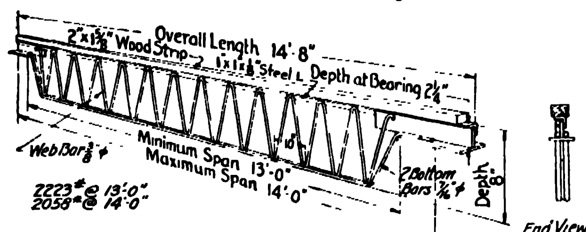


Fig. 4.—Massillon nailer joist.

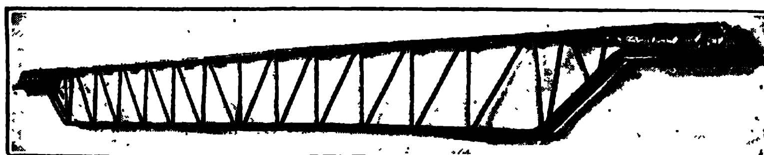


Fig. 5.—Havemeyer truss

The Macomber Steel Company also makes what is known as the "Massillon" nailer joist. It is similar in shape to the bar joist with the exception that it has a wooden member fastened to a steel angle for a top chord. It is furnished in three depths—8, 10, and 12 in.—and covers a range of spans from 4 ft. 0 in. to 26 ft. 0 in.

The Concrete Steel Company makes what is commonly known as the "Havemeyer" truss. This truss is designed as a Pratt truss with upper and lower chords consisting of two steel bars of structural-grade steel. The web members are of similar material. The end sections consist of short lengths of rolled-steel T-sections. All joints are welded. Havemeyer trusses are furnished in five depths—8, 10, 12, 14, and 16 in.—and cover a range of spans from 4 ft. 0 in. to 31 ft. 0 in.

The Truscon Steel Company, Youngstown, Ohio, makes the "Truscon O-T" (open-type) steel joists. This truss is made in the shape of the Warren truss with wide T-shaped members for chord members. The web members

are round bars. All joints are welded. The bottom chord member is continuous to the bearing where it is welded with web plate and top chord member to form a solid I-Beam. Truscon O-T joists are made in depths of 8, 10, 12, 14, and 16 in. and the span length varies from 8 ft. 0 in., to 32 ft. 0 in.

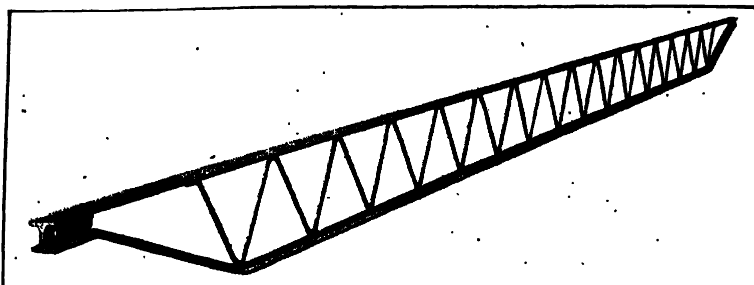


Fig. 6.—Truscon O-T steel joist.

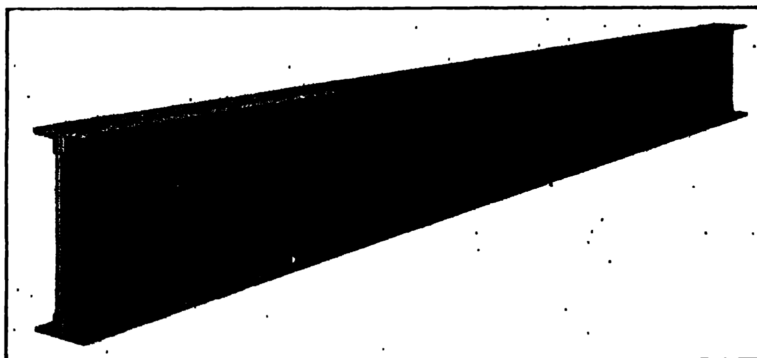


Fig. 7.—Truscon P-G steel joist.

PLATE-GIRDER JOISTS

The Truscon Steel Company makes a light-weight plate girder known as the "Truscon P-G" steel joists for floor construction. The girder consists of four light-weight structural-steel angles electrically welded to a steel web.

Properties of "P-G" Sections

Section	Depth	Flange width	Weight per foot, pounds	Thickness of metal		Moment of inertia	Section modulus
				Flange	Web		
P-G 62½	6	2½+	5.0	0.125	0.072	9.32	3.11
P-G 72½	7	2½+	5.3	0.125	0.072	13.24	3.78
P-G 82½	8	2½+	5.6	0.125	0.072	17.95	4.49
P-G 92½	9	2½+	6.1	0.125	0.083	24.15	5.37
P-G 93	9	3+	6.5	0.125	0.083	26.59	5.91
P-G 102½	10	2½+	6.8	0.125	0.095	31.78	6.36
P-G 103	10	3+	7.2	0.125	0.095	34.81	6.96
P-G 103½	10	3½+	7.6	0.125	0.095	37.88	7.58
P-G 113	11	3+	8.1	0.125	0.109	44.92	8.17
P-G 113½	11	3½+	8.5	0.125	0.109	48.64	8.84
P-G 123½	12	3½+	9.3	0.125	0.120	61.08	10.18
P-G 144	14	4+	12.0	0.125	0.134	104.52	14.93

I-BEAM JOISTS

The Truscon Steel Company makes the "Truscon" steel I-joists in the following sizes:

Truscon Steel I-Joists

Section index	Weight per lineal foot, pounds	Gage flange	Gage web	Area, square inches	Moment of inertia	Section modulus
B33	3.18	15	..	0.936	1.389	0.926
B43	3.67	15	..	1.080	2.728	1.364
B53	4.16	15	..	1.225	4.602	1.841
B63	4.89	15	15	1.440	8.133	2.711
B73	5.40	15	14	1.589	12.011	3.440
B-84-s	6.17	15	14	1 816	18.831	4.708
B84	6.77	14	14	1.992	21.030	5.258
B94-s	6.82	15	13	2.007	25.500	5 666
B94	7.42	14	13	2.183	28.646	6.366
B104-s	7.61	15	12	2.242	33.830	6 766
B105	8.80	14	12	2.581	41.895	8 379
B115	9.57	14	11	2.814	53.524	9 732
B125	10.55	14	10	3.102	66.922	11.154

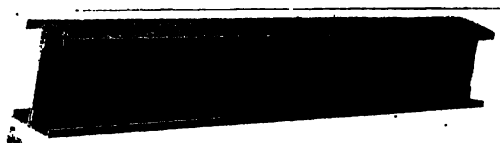


Fig. 8.—Truscon steel I-joist

The Berger Manufacturing Company, Canton, Ohio, makes an I-joist of two ro ed channels welded back to back in the following dimensions:

Depth A	Flange dimensions		Weight, pounds per lineal foot	Thickness of metal, inches	Thickness of web, inches	Area of section, square inches	Axis 1—1		
	B	C					Moment of inertia	Radius of gyration	Section modulus
4	3	½	3 7	0.072	0.144	1.08	2.60	1.552	1.30
5	3	½	4.2	0.072	0.144	1.22	4.38	1.895	1.75
6	3	½	4 7	0.072	0.144	1.37	6.90	2.244	2.30
7	3½	⅝	5 5	0.072	0.144	1.62	11.20	2.629	3.20
8	4	⅝	6 1	0.072	0.144	1.80	16.80	3.055	4.20
9	4	¾	7 0	0.075	0.150	2.06	23.85	3.403	5.30
10	4½	¾	8 0	0.078	0.156	2.38	33.25	3.738	6.65
11	4½	¾	9.5	0.086	0.172	2.80	46.20	4.062	8.40
12	4½	¾	10.5	0.090	0.180	3.10	60.00	4.399	10.00

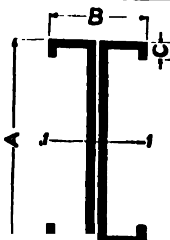


Fig. 9.—Berger I-joist.

The Jones and Laughlin Steel Corporation, Pittsburgh, Pa., makes the "J & L Junior" beam, a light-weight steel beam for use as floor beams, rafters, purlins, and studding in the following dimensions:

Depth, inches	Weight, pounds per foot	Flange Width, inches	Web thickness, inches	Area, square inches	Radius of gyration		Moment of inertia		Section modulus	
					Horizontal axis	Vertical axis	Horizontal axis	Vertical axis	Horizontal axis	Vertical axis
12	11.74	3.06	0.175	3.45	4.573	0.532	72.21	0.978	12.01	0.638
11	10.23	2.84	0.165	3.01	4.200	0.498	53.08	0.746	9.63	0.525
10	8.96	2.69	0.155	2.64	3.847	0.480	39.01	0.608	7.78	0.452
9	7.48	2.38	0.145	2.20	3.450	0.423	26.20	0.394	5.81	0.332
8	6.54	2.28	0.135	1.92	3.116	0.423	18.67	0.343	4.65	0.301
7	5.48	2.08	0.126	1.61	2.744	0.393	12.13	0.248	3.45	0.239
6	4.41	1.84	0.114	1.30	2.372	0.357	7.30	0.165	2.42	0.179

CHANNEL JOISTS

The properties of steel channels made by the Berger Manufacturing Company are as follows:

Depth A	Flange dimensions		Weight, pounds per lineal foot	Thickness of metal in inches	Area of section, square inches	Axis 1—1		
	B	C				Moment of inertia	Radius of gyration	Section modulus
4	1½	½	1.85	0.072	0.54	1.30	1.552	0.65
5	1½	½	2.10	0.072	0.61	2.19	1.895	0.88
6	1½	½	2.35	0.072	0.69	3.45	2.241	1.15
7	1¾	⅝	2.75	0.072	0.81	5.60	2.629	1.60
8	2	⅝	3.05	0.072	0.90	8.40	3.055	2.10
9	2	¾	3.50	0.075	1.03	11.93	3.403	2.65
10	2¼	¾	4.00	0.078	1.19	16.63	3.738	3.33
11	2¼	¾	4.75	0.086	1.40	23.10	4.062	4.20
12	2¼	¾	5.25	0.090	1.55	30.00	4.399	5.00

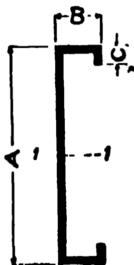


FIG. 10.—Berger channel joist.

The Truscon Steel Company makes steel channel joists and cap and sill plates in the following sizes:

TRUSCON STEEL CHANNELS

All C and P channels 15 gage; P channels fit over corresponding C channels

Section index	Weight per lineal foot, pounds	Depth, inches	Width of flange, inches
C-31½	1.59	3	1½
C-41½	1.84	4	1½
C-51½	2.08	5	1½
Cap and Sill Plates			
P-31¾	1.59	3	1¾
P-41¾	1.84	4	1¾
P-51¾	2.08	5	1¾

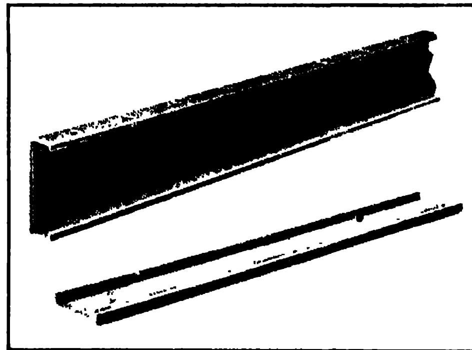


FIG. 11. *Above*, Truscon channels; *Below*, Cap and sill plates.

67. Steel Studs. The plate girder, I-beam, and channel sections described above may be used for studs in partitions and light walls (see Fig. 19). Besides these, there are a number of special sections designed for studs.

The Berger Manufacturing Company makes channel studs, U-studs, and angle studs for non-supporting partitions in the following sizes:

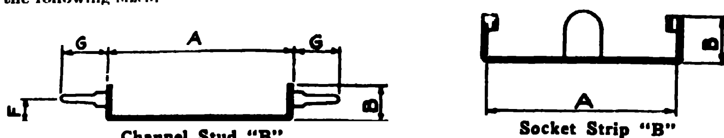


Fig. 12.—Berger channel studs and socket strips.

Channel studs "B"						Socket strips "B"			
Weight	Gage	A	B	F	G	Weight	Gage	A	B
0.58	18	2	¾	½	1	0.67	18	2	1
0.41	20					0.50	20		
0.67	18	2½	¾	½	1	0.75	18	2½	1
0.50	20					0.56	20		
0.75	18	3	¾	½	1	0.84	18	3	1
0.56	20					0.62	20		
0.84	18	3½	¾	½	1	0.92	18	3½	1
0.62	20					0.69	20		
0.92	18	4	¾	½	1	1.00	18	4	1
0.69	20					0.75	20		

Lengths over 12 ft. 0 in. long require splices.

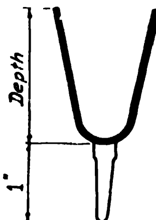


Fig. 13.—Berger U-studs.

Depth, inches	Gage	Weight per foot	
		Black	Galvanized
¾	20	0.25	0.28
1	20	0.31	0.35
1¼	20	0.38	0.41
1½	20	0.44	0.48
1¾	20	0.50	0.55
2	20	0.56	0.62
¾	18	0.33	0.36
1	18	0.42	0.45
1¼	18	0.50	0.54
1½	18	0.58	0.63
1¾	18	0.67	0.72
2	18	0.75	0.81

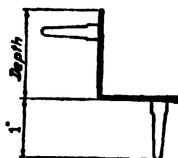


Fig. 14.—Berger angle studs.

Size, inches	Gage	Weight per foot	
		Black	Galvanized
1¼ × 1¼	20	0.31	0.34
1½ × 1½	20	0.38	0.41
1¼ × 1¼	18	0.42	0.45
1½ × 1½	18	0.50	0.54

Use same track as for U-studs.
Lengths over 12 ft. require splices.

The Berger Company also makes a heavier I-section and a channel section for supporting partitions.

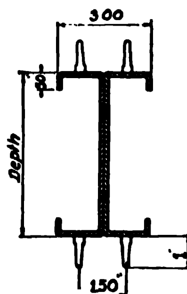


Fig. 15.—Berger-I-stud.

Depth, inches	Weight per foot, pounds	Flange width, inches	Thickness metal, inches	Thickness web, inches	Net area of section, square inches
4	3.60	3.00	0.072	0.144	0.972
4	6.00	3.00	0.120	0.240	1.620
5	4.10	3 00	0.072	0.144	1.116
5	6.80	3.00	0.120	0.240	1.860
6	4.60	3.00	0.072	0.144	1.260
6	7.60	3.00	0.120	0.240	2.100
7	5.30	3.50	0.072	0.144	1.476
7	8.80	3.50	0.120	0.240	2.460
8	6.00	4.00	0.072	0.144	1.692
8	10.00	4.00	0.120	0.240	2.820

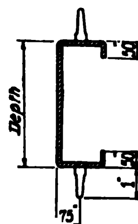


Fig. 16.—Berger channel stud.

Depth, inches	Weight per foot, pounds	Flange width, inches	Thickness of metal, inches	Net area of section, square inches
4	1.80	1½	0.072	0.486
4	3.00	1½	0.120	0.810
5	2.05	1½	0.072	0.558
5	3.40	1½	0.120	0.930
6	2.30	1½	0.072	0.630
6	3.80	1½	0.120	1.050
7	2.65	1¾	0.072	0.738
7	4.10	1¾	0.120	1.230
8	3.00	2	0.072	0.846
8	5.00	2	0.120	1.410

The "Milcor" cold-rolled steel channels, made by the Milwaukee Corrugating Company, Milwaukee, Wis., are used for solid and hollow-stud partitions and for suspended ceilings (see p. 965). Milcor channels are furnished in the following dimensions:

	Weight per 1000 Lin. Ft
¾ in	276 lb.
1 in	332 lb.
1½ in	456 lb.
2 in	552 lb.
Cubro channels	270 lb.

Depth of legs on ¾, 1, 1½ and 2-in. channels, ⅜ in ; on Cubro channels, ⅝ in.

¾-in. and Cubro channels are furnished in stock lengths of 12, 14, 16, 18, and 20 ft., packed 20 channels to a bundle. 1, 1½, and 2-in. channels are furnished in stock lengths of 16, 18 and 20 ft., packed 10 channels to a bundle.

68. Steel Roof Deck.—The steel plate makes a fairly strong, light-weight roof and is fireproof. They can be used on practically any type of roof, being best suited for flat, pitched, and curved roofs. The sections are convenient for handling and can be quickly placed. All joints should be made directly over the roof purlins. The plates are fastened to purlins by means of special clips.

The R. C. Mahon Company, Detroit, Mich., makes a copper bearing steel deck plate of either 18 or 20 gage steel. A galvanised-steel plate is also furnished on special orders. All plates lay 12 in. wide when installed, ribs 1½ in. deep, and 6 in. on centers. The ribs supply structural strength to the plates. Fig. 20 shows the Mahon Standard roof deck plate and the construction details. The table on p. 966 gives the plate lengths for different purlin spacings.

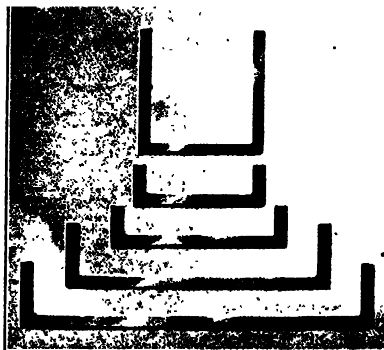


Fig. 17.—Milcor channel studs.

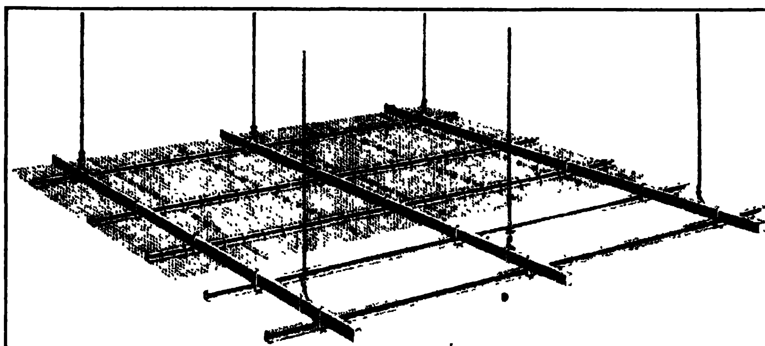


Fig. 18.—Suspended ceiling of Milcor channels

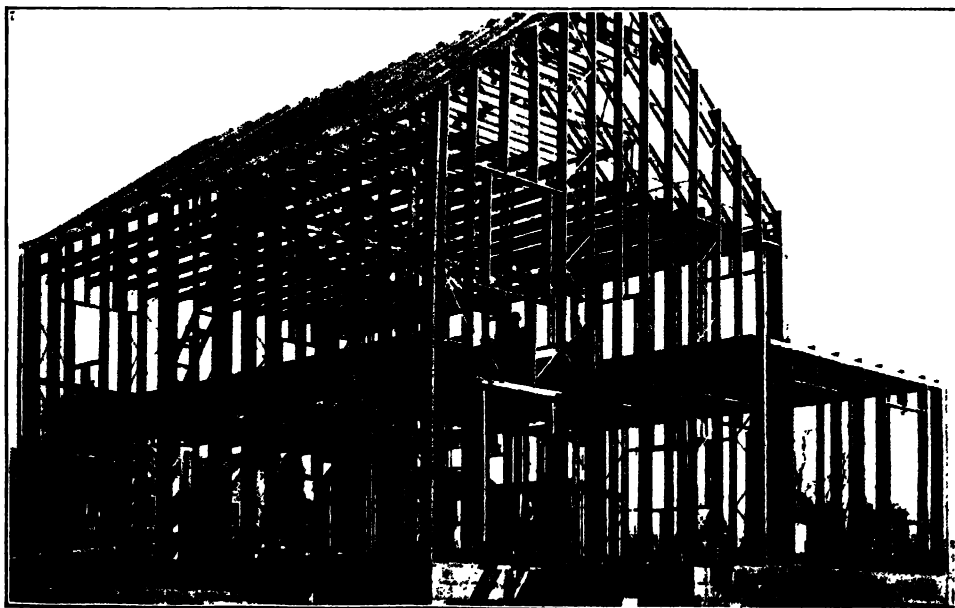


Fig. 19.—J & L Junior beams used for studding, rafters and floor joist in the C. L. Workman House, Pittsburgh, Pa.

Table of Standard Deck Plates Recommended for Various Purlin Spacing

Purlin spacing	Plate lengths
to 4 ft. 0 in.	8 ft. 4 in. or 12 ft. 4 in.
4 ft. 0 in. to 5 ft. 0 in.	5 ft. 2 in. or 10 ft. 4 in.
5 ft. 0 in. to 6 ft. 0 in.	6 ft. 2 in. or 12 ft. 4 in.
6 ft. 0 in. to 7 ft. 0 in.	7 ft. 2 in.
7 ft. 0 in. to 8 ft. 0 in.	8 ft. 4 in.

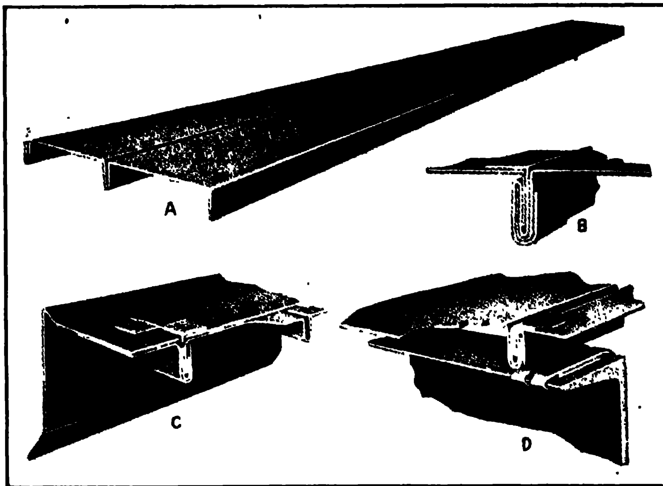


Fig. 20.—Mahon standard roof deck plate and details of construction.

The Truscon Steel Company furnishes the "Truscon" I-plates for steel deck roofs in either 18- or 20-gage copper bearing steel. The plates are 2 ft. 0 in. wide and are furnished in standard lengths of 8 and 10 ft. Special lengths are furnished on request with 10 ft. as a maximum. The I-sections are 1 in. deep, have a bottom flange ⅝ in. wide, and are spaced 6 in. on centers. The I-sections supply structural strength to the plates. Fig. 21 shows the Truscon I-plates in place. The following table gives the allowable spans (purlin to purlin) for different live loads:

The Dead Load Is Provided for in This Tabulation

Live loads, pounds square foot	Spans, purlin to purlin	
	18 gage	20 gage
45	6 ft. 9 in.	5 ft. 8 in.
40	7 ft. 0 in.	6 ft. 0 in.
35	7 ft. 6 in.	6 ft. 4 in.
30	8 ft. 0 in.	6 ft. 10 in.
25	8 ft. 8 in.	7 ft. 6 in.
20	9 ft. 6 in.	8 ft. 2 in.

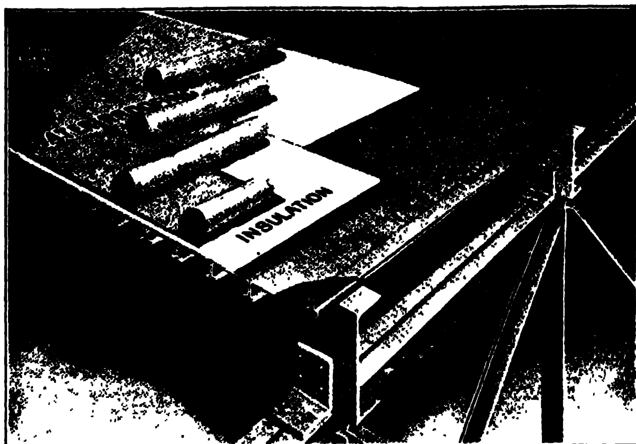


Fig. 21.—Truscon I-plates in place.

METAL LATH

By H. E. Pulver

The general function of metal lath is to form a support, background, or base, to which plaster or stucco may be applied. It is also by itself put to other uses, such as making lockers, register faces, etc. In its larger sizes and weights, it is used for reinforcement in concrete (see chapter on Concrete Reinforcement).

All metal lath is furnished painted, asphaltum dipped, or galvanized, the earlier practice of furnishing the material untreated having been discontinued by the manufacturers. Galvanized metal lath is either manufactured from galvanized sheets or galvanized after manufacture. In this article only a few of the many kinds of metal lath on the market will be described.

69. Kinds of Metal Lath. - Metal lath may be classified as follows:

1. Expanded metal lath:
   - Diamond and rectangular mesh.
   - Ribbed lath.
   - Corrugated lath.
2. Integral lath, reinforced or stiffened, combining the functions of lath and studding:
   - Expanded.
   - Sheet, not expanded.
3. Sheet lath:
   - Flat perforated.
4. Wire lath, woven or welded:
   - Plain.
   - Ribbed.

69a. Expanded Metal Lath.

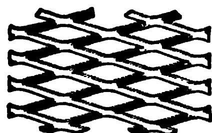


Fig. 22.—Expanded metal lath diamond mesh.

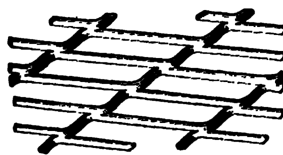


Fig. 23.—Expanded metal lath, rectangular mesh.

DIAMOND AND RECTANGULAR MESA

The Berger Manufacturing Company, Canton, Ohio, furnishes diamond-mesh lath as follows:

Weight per square yard, pounds	Size of sheets, inches	Square yards per sheet	Sheets per bundle	Square yards per bundle
2.2	24 × 96	1.78	9	16
2.5	24 × 96	1.78	9	16
3.0	24 × 96	1.78	9	16
3.4	24 × 96	1.78	9	16

The above weights apply to *painted steel, painted copper bearing*, and *painted Toncan metal lath*. Diamond mesh lath can also be furnished cut from *galvanized sheets* in 2.5- and 3.4-lb. weights.

The Bostwick Steel Lath Company, Niles, Ohio, makes the "Niles" flat expanded metal lath according to the U. S. Department of Commerce, Simplified Practice Recommendation No. 3.

Bostwick Niles Lath

Sizes, inches		Sheets per bundle	Yards per bundle	Weight per square yard, pounds
Width	Length			
24	96	9	16	3.40
24	96	9	16	3.00
24	96	9	16	2.50
24	96	9	16	2.20

The Sykes Metal Lath Co., Niles, Ohio, makes an "Economy" diamond metal lath in sheets 27 ×96 in. and in the following weights: 2.2, 2.5, 3.0, and 3.4 lb. per sq. yd., painted, and 2.5 and 3.4 lb. per sq. yd., galvanized. This company also makes a "Coppersyke" diamond metal lath (high copper content, Bessemer steel) in the 2.5 and 3.4 lb. per sq. yd. weights.

The General Fireproofing Company, Youngstown, Ohio, makes "Key expanded met al lath" as follows.

Key Expanded Metal Lath

Weights per Square Yard, Measurements, and Domestic Packings

Weights per square yard, pounds			Domestic packing			
			Size of sheets, inches	Sheets per bundle	Number of square yards	
Painted	Galvanized	Armco			Per sheet	Per bundle
2.2		2.2	24 × 96	9	$1\frac{7}{9}$	16
2.5	2.5	2.5	24 × 96	9	$1\frac{7}{9}$	16
3.0	..	3.0	24 × 96	9	$1\frac{7}{9}$	16
3.4	3.4	3.4	24 × 96	9	$1\frac{7}{9}$	16

The Northwestern Expanded Metal Company, Chicago, Ill., manufactures the following brands of flat expanded metal lath:

"Kno-burn" metal lath, a painted ⅜-in. diamond meshed steel bar.

"XX Century" copper bearing metal lath of same sizes and weights as *Kno-burn*.

"Galvanized" metal lath of same sizes and weights as *Kno-burn*.

"Pure iron" metal lath painted red and of the same sizes and weights as *Kno-burn*.

All brands conform to the standard weights and sizes.

Stock Size and Weights for Kno-burn and XX Century Lath

Weight per square yard, pounds	Size of sheets	Sheets per bundle
3.4*†	24 × 96	9(16 yards)
3.0*	24 × 96	9(16 yards)
2.5*†	24 × 96	9(16 yards)
2.2	24 × 96	9(16 yards)

* Pure Iron lath furnished in these weights.
† Galvanized lath furnished in these weights.

The Youngstown Pressed Steel Company of Warren, Ohio, manufacture "Mahoning" brand of metal lath.

Mahoning Metal Lath

Weight per square yard, pounds			Sheets per bundle	Yards per bundle	Size sheets, inches
Steel	Copper alloy	Galvanized			
2.2	2.2	.	9	16	24 × 96
2.5	2.5	2.5	9	16	24 × 96
3.0	3.0	.	9	16	24 × 96
3.4	3.4	3.4	9	16	24 × 96

The Milwaukee Corrugating Company, Milwaukee, Wis., manufacture following brand of "Netmesh" diamond expanded lath.

Netmesh Diamond Expanded Lath 3/8" Mesh

Type	Weight per square yard, pounds	Size of sheets, inches	Number of sheets in bundle	Square yards in bundle	Weight per bundle, pounds
Cut from black steel sheets painted black. All of our painted metal lath is heat treated and re-annealed after being cut and expanded, giving the metal longer life and greater strength. Our Milcor special elastic paint adds further protection.	2.20	24 × 96	9	16	35
	2.50	24 × 96	9	16	40
	3.00	24 × 96	9	16	48
	3.40	24 × 96	9	16	54
Cut from coppered metal painted red.......	2.20	24 × 96	9	16	35
	2.50	24 × 96	9	16	40
	3.00	24 × 96	9	16	48
	3.40	24 × 96	9	16	54
Cut from galvanized open-hearth steel sheets......	2.50	24 × 96	9	16	40
	3.40	24 × 96	9	16	54
Cut from pure zinc....... . . .	3.03	24 × 96	9	16	48
Cut from cold-rolled copper...	3.31	24 × 96	9	16	53

Also furnished in "Armco" ingot iron, 2.50 and 3.40 lb. only, painted red or cut from galvanized armco ingot iron.

The Truscon Steel Company, Youngstown, Ohio, makes a "Truscon" diamond lath in open-hearth or copper-bearing steel, painted, or galvanized before expansion.

Truscon Diamond Lath

2 yd. per sheet; size of sheet, 27 × 96 in.

Gage number	Sheets per bundle	Yards per bundle	Weight per square yard, painted, pounds	Weight per square yard, galvanized, pounds
27	10	20	2.33	2.50
26	10	20	2.55	
25	10	20	3.00	
24	10	20	3.40	3.60

RIBBED LATH

The General Fireproofing Company, Youngstown, Ohio, is the manufacturer of "Herringbone" metal lath "Herringbone" double-mesh metal lath, and "GF" diamond rib metal lath.

Herringbone metal lath is made of Armco ingot iron in 20½ × 96-in. sheets and packed 15 sheets (22½ yd.) to the bundle. The weights per square yard are 2.2, 2.5, 3.0, and 3.4 lb.

Herringbone double-mesh metal lath is made of Armco ingot iron in 3.0 lb. per sq. yd. weight, 15 in. × 96 in. sheets, and packed 18 sheets to the bundle. It is also made in 3.4 lb. per sq. yd. weight, 24 in. × 96 in. sheets, and 9 sheets to the bundle.

GF diamond rib metal lath is made in 24 × 96 in. sheets with ribs spaced 4.8 in. on centers. It is packed 9 sheets (16 yd.) per bundle. The weights per square yard in painted-steel lath are 2.5, 3.0, 3.5, and 4.0 lb. The Armco ingot iron lath is made in 3.5 and 4.0 lb. per sq. yd. weights.

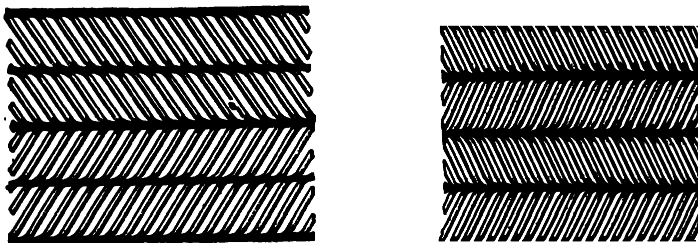


Fig. 24.—Herringbone expanded metal lath, two types.

The Northwestern Expanded Metal Company, Chicago, Ill., makes two styles of ribbed lath. The "Plasta-Saver" metal lath is a ⅛-in. flat rib of painted-steel base or copper-bearing sheet of 3.4 lb. per sq. yd., 24 × 96 in. sheets, and 9 sheets per bundle. The ⅜-in. "Longspan" rib lath is of painted-steel base with a 4-in. rib spacing. Sheets are 24 × 96 in. in size and are packed 9 to the bundle. This lath is made in weights of 3.0, 3.5, and 4.0 lb. per sq. yd. Pure iron sheet may be had in the 4.0 lb. weight.

The Bostwick Steel Lath Company, Niles, Ohio, makes a ⅜-in. rib expanded metal lath with ribs spaced every 4 in. This lath is furnished in 24 × 96-in. sheets and in weights of 2.5, 3.0, 3.5, and 4.0 lb. per sq. yd.

The Berger Manufacturing Company, Canton, Ohio, makes a Berloy ⅜-in. "Ribplex" lath, as described in the following table:

Sections across ⅜-in. Ribplex Sheet. Ribs are ⅜-in. high spaced 8 in. on centers				
Weight per square yard, pounds	Size of sheets, inches	Square yards per sheet	Sheets per bundle	Square yards per bundle
3.0	24 × 102	1.89	9	17
3.5	24 × 102	1.89	9	17
4.0	24 × 102	1.89	9	17

The above weights apply to *painted steel* and to *painted Toncan metal* ⅜-in. Ribplex. *Toncan metal* ⅜-in. Ribplex, however, is made in only the 3.5 and 4.0 lb. weights.

The Milwaukee Corrugating Company, Milwaukee, Wis., manufactures the "Milcor Stay-rib" metal lath in three grades. The ¾-in. grade is described in the article on Concrete Reinforcement. The Milcor lath in the following tables is made in 24 × 96 in. sheets, with 9 sheets (16 sq. yd.) to the bundle:

Milcor Stay-rib Metal Lath No. 1

Type	Weight per square yard, pounds	Weight per bundle, pounds
Cut from open-hearth steel sheets, painted....	2.75 3.20 3.50 4.00	44 51 56 64
Also, furnished cut from coppered metal. All our painted lath is heat treated and re-annealed after being cut and expanded, which gives the metal longer life and greater strength.		
Cut from galvanized open-hearth steel sheets.....................	3.60	57

Furnished in Armco ingot iron, both painted and galvanized.

Milcor ⅜ inch Stay-rib Metal Lath No. 2

Type	Weight per square yard, pounds	Weight per bundle, pounds
Cut from open-hearth steel sheets, painted...........	2.75 3.00 3.50 4.00	44 48 56 64
Also, furnished cut from coppered metal. All our painted lath is heat treated and re-annealed after being cut and expanded, to give the metal longer life and greater strength.		
Cut from galvanized open-hearth steel sheets....................	3.60	57

Furnished in Armco ingot iron, in 3.50 and 4.00 lb. painted. Also, 4.00 lb. galvanized.

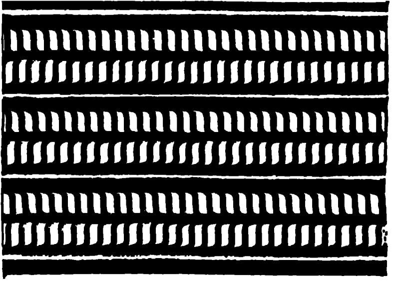


Fig. 25.—Milcor stay-rib metal lath No. 1.

The Youngstown Pressed Steel Company, Warren, Ohio, makes two kinds of rib lath. All sheets are 24 × 96 in. in size and packed 9 to the bundle.

The "*Ideal*" *rib lath* of painted steel with rib intervals of 4 in. is made in the 2.5, 3.0, 3.5, and 4.0 lb. per sq. yd. weights. This lath is also furnished in copper alloy in the 3.0 and 3.5 lb. weights.

The "*YPS Z-Rib*" *Lath* has ribs ⅜ in. wide and 1½ in. in centers. This lath is furnished in the 3.0 and 3.4 lb. per sq. yd. weights.

The Truscon Steel Company, Youngstown, Ohio, makes the "*Standard*" *rib lath* in 27 × 96 in. sheets in weights of 2.64, 3.17, and 4.23 lb per sq. yd.

This company makes the "*A Hy-rib*" *Lath* in 18 × 96-in. sheets in the 3.2 lb. per sq. yd. weights.

Truscon ⅜-in. "*Hy-rib*" *Lath* is made in 24 in. × 6, 8, 10, or 12 ft. sheets, with ribs spaced 4 in. on centers, and in the 3.0, 3.5, and 4.0 lb. per sq. yd. weights. Truscon lath is furnished in painted open-hearth or copper-bearing steel.

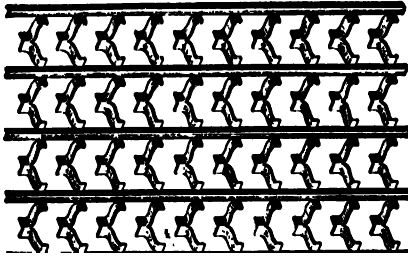


Fig. 26.—Standard rib lath.

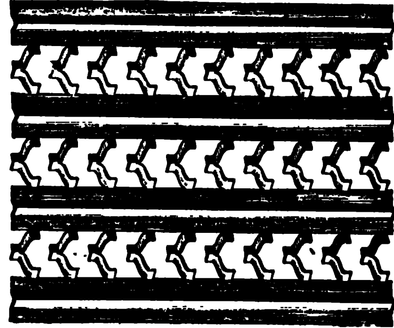


Fig. 27.—Type A rib lath.

CORRUGATED LATH

The Youngstown Pressed Steel Company, Warren, Ohio, makes a "Zee" self-ferring or corrugated lath which has the same mesh and properties as the Mahoning diamond lath.

The Berger Manufacturing Company, Canton, Ohio, makes a corrugated diamond inch lath which is the same as their diamond inch lath with corrugations added.

The Bostwick Steel Lath Company, Niles, Ohio, makes a self-furring or Bostwick "Lock' corrugated lath which has the same weights and sizes as their Niles expanded lath.

The Truscon Steel Company, Youngstown, Ohio, makes a self-furring diamond lath which is their Truscon diamond lath with domelike projections formed in the lath 1½ in. in diameter and ¾ in. high that act as furring.

The Sykes Metal Lath Co., Niles, Ohio, makes an expanded cup metal lath in the following weights: 2.5 and 3.4 lb. per sq. yd. painted and 3.0 and 3.4 lb. per sq. yd. galvanized. Sheets are 18 × 96 in. in size.

The Northwestern Expanded Metal Company, Chicago, Ill., makes a corrugated or self-furring metal lath having the same sizes and weights as their Kno-burn lath

The Milwaukee Corrugating Company, Milwaukee, Wis., makes a corrugated Netmesh lath which is similar to their Netmesh diamond expanded metal lath. This corrugated lath is cut from black steel sheets re-annealed and painted black after expanded in the 2.20, 2.50, and 3.40 lb. weights, from galvanized open-hearth steel sheets in the 2.50 and 3.40 lb. weights, from coppered metal in the 2.20, 2.50, and 3.40 lb. weights, and from Armco ingot iron in the 2.50 and 3.40 lb. weights only.

69b. Integral Lath.—Reinforced or stiffened, combining the functions of lath and studding, is a ribbed expanded metal reinforcement used for the construction of concrete roofs, walls, partitions, ceilings, etc. For roofs and floors it acts as both form and reinforcement. For walls and partitions it combines the functions of lath and studding. For ceilings it is a one-piece lath and furring.

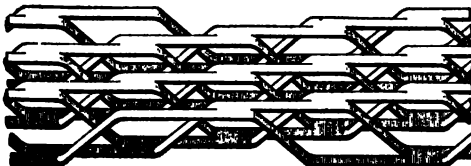


Fig. 28.—Truss metal lath.

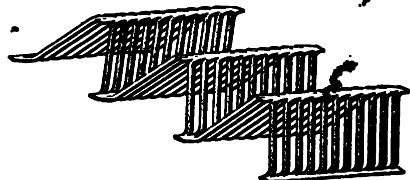


Fig. 29.—"Trussit."

Sheet is not expanded. It is a fabric having the same functions as one stiffened, in which the openings between the ribs are made by punching or perforating the sheet rather than expanding it laterally.

The American Rolling Mill Company, Middletown, Ohio, makes *truss metal lath* (Fig. 28). Stock size sheets 28 × 96 in. equal to 17½ sq. ft. Packed in crates containing 350 sq. ft. Special size sheets are furnished when desired. No. 26 gage weighs 80 lb. per 100 sq. ft. and No. 28 gage weighs 66.7 lb. per 100 sq. ft. Furnished in Armco iron or steel.

The General Fireproofing Company, Youngstown, Ohio, makes *Self-Sentering* (see Art. 134, and Fig. 44, p. 1017).

This company also makes a fabric known as "*Trussit*" in sheets (Fig. 29), the standard size of which is 19 in. wide. It is carried in stock lengths of 8, 10, and 12 ft.—packed 10 sheets to a bundle.

Gage number	Weight painted per sq. ft., pounds	Weight galvanized per sq. ft., pounds
27	0.57	0.68
26	0.62	0.73
24	0.83	0.88

The Truscon Steel Company, Youngstown, Ohio, is the manufacturer of "*Hy-rib*," of which there are two types.

The Bostwick Steel Lath Company, Niles, Ohio, makes a "Truss V-rib" reinforced metal lath furr open-hearth sheet. The ribs are ¾ in. high at 7-in. intervals. Size of sheets is 21 in. wide by 4, 5, 6, 7, 8, 9, and 10 ft. long. The lath is made in No. 24-, 26-, or 28-gage metal.

69c. Sheet Lath.—The Berger Manufacturing Company, Canton, Ohio, makes a "Berloy" sheet lath which is a perforated sheet-metal lath not expanded. Sheets are 18 × 96 in. in size, and the weight of each is 4.50 lb. per sq. yd.

The Bostwick Steel Lath Company, Niles, Ohio, makes a "truss-loop" metal lath having 652 truss loops per square yard. This lath is made in the 4.5 lb. per sq. yd. weight, painted, and 5.5 lb. per sq. yd. weight galvanized.

The Sykes Metal Lath Co., Niles, Ohio, makes a trough sheet-metal lath in the following weights: painted 4.5 lb. per sq. yd., and galvanized 5.5 lb. per sq. yd. Sizes of sheets are 13.5 × 96 in. and 24 × 96 in.

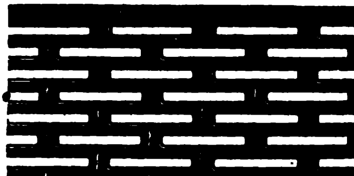


Fig. 30.—Berloy sheet lath.

69d. Wire Lath.—Woven wire lath is manufactured by several companies and is supplied painted or galvanized after weaving. Some of the companies manufacturing this type of lath are the New Jersey Wire Cloth Company, Trenton, N. J., and the Wickwire Spencer Steel Company, New York City. The wire lath may or may not have ribs, which are either rods or V-shaped metal strips running through the wire mesh to keep the fabric away from the face of the timbers so that mortar will pass behind the fabric and also to stiffen and reinforce it. The gages used are Nos. 18, 19, and 20, either with or without ribs. The weights per square yard are practically the same as those recommended by the Associated Metal Lath Manufacturers.

Welded wire lath (usually electrically welded) is now being manufactured by several companies, such as The National Steel Fabric Company, Pittsburgh, Pa., American Steel and Wire Company, Chicago, Ill., Truscon Steel Company, Youngstown, Ohio, and the Wickwire Spencer Steel Corporation, Buffalo, N. Y. One product, "Steeltex," manufactured by the National Steel Fabric Company, consists of a comparatively light, electrically welded fabric integrally combined with a tough waterproof backing.

70. General Uses.—Metal lath is used for lathing ceilings, walls, and partitions of wood-joisted and studded buildings; for suspended ceilings, solid partitions, hollow partitions, and ornamental plastering in the fire-resistive type of buildings; and as a base for exterior stucco on houses, barns, garages, and other types of frame buildings. Integral lath may be used as a form and reinforcement for light floor and roof slabs, as may also other special types of lath made by different manufacturers. Metal lath has developed from a specialty in fireproof construction to a staple base for plastering in every type of building. Fabrics expanded from heavier sheets of metal are largely used for reinforcing floors, walls, roads, pavements, etc.

When used against masonry walls, metal lath is applied either to wood furring strips, or to furring consisting of $\frac{3}{16}$-in. pencil rods or ½-in. crimped furring, so as to insure a "key"

for the plaster and provide the requisite air space. When the integral type is used, furring is not required, as the ribs act as furring.

When expanded metal lath is used for solid partitions, suitable small structural steel members, usually ¾ or 1-in. channels are used as studs. The integral type of lath with ribs ¾ in. or more deep may be used without studs.

When metal lath is used on suspended ceilings and for ornamental plastering work, a supporting structural frame of flats, angles, and channels should be specifically called for. Where integral lath is used, the auxiliary channels for support may be omitted as the ribs support and stiffen the lath so that it may be attached directly to the flats or angles.

Metal lath and metal-lath construction should preferably conform, in general, with the U. S. Department of Commerce Simplified Practice Recommendations and the Specifications for Metal Lath Construction approved by the Associated Metal Lath Manufacturers and the American Specification Institute.

The following extracts from the above specifications will give an idea of the weights of metal lath used for different kinds of construction:

WEIGHTS OF METAL LATH

1. Wood-stud and Joist Construction

(a) *For Partitions.*—Expanded metal lath, for studs with a maximum spacing of 16 in. on centers, shall weigh not less than 2.5 lb. per sq. yd.

NOTE.—Expanded metal lath weighing 2.2 lb. per sq. yd. is regularly manufactured and available for use in partitions where Underwriter's Standards are not exacted; it is also suitable for corner reinforcements (cornerite).

Three-eighths-inch rib lath, for studs with a maximum spacing of 19½ and 24 in. on centers, shall weigh not less than 2.5 and 3 lb. per sq. yd. respectively.

Flat rib lath, for studs with a maximum spacing of 19½ in. on centers, shall weigh not less than 3 lb. per sq. yd.

(b) *For Ceilings.*—Expanded metal lath, for joists with a maximum spacing of 16 in. on centers, shall weigh not less than 3 lb. per sq. yd.

Three-eighths-inch rib lath, for joists with a maximum spacing of 19½ and 24 in. on centers, shall weigh not less than 3 and 3.5 lb. per sq. yd. respectively.

Flat rib lath, for joists with a maximum spacing of 19½ in. on centers, shall weigh not less than 3 lb. per sq. yd.

2. Back-plastered Metal-lath Stucco Construction

Expanded metal, self-furring, or ⅜-in. rib lath, for studs not greater than 16 in. on centers, shall weigh not less than 3.4 lb. per sq. yd.

3. Stucco on Metal Lath or Expanded Metal Reinforcing over Sheathing

(Same as Specification 2, or use expanded metal reinforcing weighing not less than 0.2 lb. per sq. ft. with a minimum opening of 1½ in.)

4. Overcoating Stucco on Metal Lath

(Same as Specification 3, stucco over sheathing.)

5. Metal Stud Partitions (Solid or Hollow)

(a) Expanded metal lath, for studs with a maximum spacing of 12 in. on center, shall weigh not less than 2.2 lb. per sq. yd., and for studs with a maximum spacing of 16 in. on center shall weigh not less than 2.5 lb. per sq. yd.

(b) Three-eighths-inch rib lath, for studs with a maximum spacing of 19½, 24, 30, and 36 in. on centers, shall weigh not less than 2.5, 3, 3.5, and 4 lb. per sq. yd.

(c) Flat rib lath, for studs with a maximum spacing of 19½ in. on center, shall weigh not less than 3 lb. per sq. yd.

6. Metal Stud Partitions (in Buildings with Wood Floors or Wood Ceiling Joists)

In buildings with wood floors or with wood-floor joists, solid or hollow channel stud partitions shall be constructed in precisely the same manner as in buildings with incombustible floors or ceilings (see specification 5), except that when floor and ceiling runners are used they shall be spiked directly to the wood floor or the ceiling joists, provided, also, that certain alternate methods of securing the channels to the wood floors shall be permissible.

7. Wall Furring

(a) Expanded metal lath, for vertical furring channels with a maximum spacing of 12 and 16 in. on centers, shall weigh not less than 2.2 and 2.5 lb. per sq. yd. respectively.

(b) Three-eighths-inch rib lath, for vertical furring channels with a maximum spacing of 19½, 24, 30 and 36 in. on centers, shall weigh not less than 2.5, 3, 3.5, and 4 lb. per sq. yd. respectively.

(c) Flat rib lath for vertical furring channels with a maximum spacing of 19½ in. on centers shall weigh not less than 3 lb. per sq. yd.

8. Standing Furring

Standing furring shall have same spacing of studs and same weight of lath as used for solid metal stud partitions (Specification 5).

9. Attached Ceilings Clipped to Steel Floor Beams or in Contact with Concrete or Terra Cotta Floors

Expanded metal lath, for furring channels with a maximum spacing of 12 and 16 in. on centers, shall weigh not less than 3 and 3.4 lb. per sq. yd. respectively. Three-eighths-inch rib lath, for furring channels with a maximum spacing of 19½, 24, and 30 in. on centers, shall weigh not less than 3, 3.5, and 4 lb. per sq. yd. respectively. Flat rib lath for furring channels with a maximum spacing of 19½ in. centers shall weigh not less than 3 lb. per sq. yd.

10. Attached Ceilings under Concrete Joists and Floors Constructed with Removable Metal Tiles, Domes, or Pans

NOTE.—Construction outlined in Specification 9 preceding can be adapted for attached ceilings under concrete joists and floors.

SIZE, WEIGHT, SPACING, AND ERECTION OF FURRING CHANNELS AND RODS—WEIGHTS OF METAL LATH (METHOD A)

Pencil rods shall be spaced not to exceed 11¾-in. centers for 3-lb. expanded metal lath or 15¾-in. centers for 3.4-lb. expanded metal lath, or 19½-in. centers for flat rib lath or ⅜-in. rib lath weighing not less than 3 lb. per sq. yd. Where ⅜-in. rib lath weighing not less than 3.5 lb. per sq. yd. is used, the pencil rods may be omitted.

SIZE, SPACING, AND ERECTION OF HANGERS AND PENCIL RODS—WEIGHTS OF METAL LATH (METHOD B)

(a) In lieu of attachment to channels, pencil rods not less than ¼ in. in diameter shall be attached directly to wire hangers cast into the concrete joists. Pencil rods shall be placed at right angles to the joists.

(b) Hangers shall be not less than No. 14 gage galvanized annealed wire and shall be spaced not to exceed 11¾-in. centers for 3-lb. expanded metal lath, 15¾-in. centers for 3.4-lb. expanded metal lath, or 19½-in. centers for 3-lb. flat rib or ⅜-in. rib lath.

(c) Where ⅜-in. rib lath, weighing not less than 3.5 lb. per sq. yd., is used, the pencil rods may be omitted, but the ribs of the lath shall be placed at right angles to the joists, and attachments shall be spaced not to exceed 6 in. on centers along joists.

11. Attached Ceilings under Concrete Joists and Floors, Constructed with Permanent Metal Tiles, Domes, or Pans

Methods of attachment and sizes and weights of the component parts of this form of construction shall be in accordance with the specifications of the manufacturers of the metal tiles, domes, or pans.

12. Suspended Ceilings

SUSPENDED BELOW THE SOFFIT OF STEEL OR CONCRETE BEAMS OR PURLINS CONCRETE OR HOLLOW-TILE FLOOR ARCHES

Suspended below the Soffit of Steel or Concrete Beams or Purlins or Concrete or Hollow-tile Floor Arches.

No metal lath used for suspended ceilings shall have a weight less than 3 lb. per sq. yd.; provided, however, that minimum weights shall, in each case, be governed by spacing of furring channels.

13. Beams and Cornices

Expanded metal lath, for beams and cornices where brackets are spaced 12 or 16 in. on centers, shall be not less than 2.5 and 3 lb. per sq. yd. respectively.

14. Columns and Pilasters

(a) Expanded metal lath, where vertical members of framing are spaced not to exceed 12 or 16 in., shall weigh not less than 2.5 and 3 lb. per sq. yd. respectively.

(b) Three-eighths-inch rib or flat rib lath, where vertical framing members are spaced not to exceed 19½, 24, and 30 in. on centers, shall weigh not less than 2.5, 3, and 3.5 lb. per sq. yd. respectively.

15. Metal Lath in Steel Joist Construction

(a) Flat expanded metal lath used on the upper (floor) side of steel joists (metal lumber) with a maximum spacing of 16 and 12 in. shall weigh not less than 3.4 lb. and 3 lb. per sq. yd. respectively.

(b) Three-eighths-inch rib lath used on the upper (floor) side of steel joists, with a maximum spacing of 24 in., shall weigh not less than 4 lb. per sq. yd.

(c) Expanded metal lath for ceilings attached in contact with the lower flanges of steel joists with a maximum spacing of 16 and 12 in. shall weigh not less than 3.4 and 3 lb. per sq. yd respectively. Three-eighths-inch rib lath used for the same purpose, for joists with a maximum spacing of 19½, 24, and 30 in. on centers, shall weigh not less than 3, 3.5, and 4 lb. per sq. yd. respectively. Flat rib lath, for steel joists with a maximum spacing of 19½ in. centers, shall weigh not less than 3 lb. per sq. yd.

For illustrated details for metal-lath construction, see "Specifications for Metal Lath Construction" published by the Associated Metal Lath Manufacturers, Inc.

71. Weight and Gage.—It is recommended that metal lath be specified by weight as well as by gage. The manufacturers are standardizing metal lath at the following weights for the gages given:

Gage	Pounds per square yard
24	3.4
25	3.0
26	2.5
27	2.2

LIME, LIME MORTAR, AND LIME PLASTER

By D. Knickerbacker Boyd

72. Quicklime and Its Manufacture.—Lime is the product resulting from the calcination or "burning" of limestone. It has been defined by the American Society for Testing Materials[1] as follows:

Quicklime. A calcined material, the major part of which is calcium oxide or calcium oxide in natural association with a lesser amount of magnesium oxide, capable of slaking with water.

Limestone is found in nearly every state in the Union and is of two distinct types—one containing up to 98% of calcium carbonate with little or no magnesium carbonate; and the other containing magnesium carbonate in quantities ranging as high as 84 parts magnesium carbonate to 100 parts of calcium carbonate. Limestones containing 10% or more of magnesium carbonate are generally known as "magnesium" limestones. Those containing in excess of 25% magnesium carbonate are usually referred to as "dolomitic" limestones. Limestones containing less than 10% of magnesium carbonate are usually referred to as "high-calcium" limestones.

Limestone may be considered as being composed of calcium oxide (CaO) and carbon dioxide (CO_2)—these constituents forming calcium carbonate ($CaCO_3$) which is the form in which all limestone is found. Chemically pure high calcium limestone would be composed of 56 % of calcium oxide and 44 % carbon dioxide by weight. Chemically pure dolomitic limestone would be composed of 30.43 % calcium oxide, 21.74 % magnesium oxide, and 47.83 % carbon dioxide by weight.

The lime resulting from the calcination or "burning" of these limestones is known either as high-calcium lime, magnesium lime, or dolomitic lime, depending upon the character of the limestone from which it is obtained. Although each of these kinds of lime requires a different proportion of sand or other ingredients and varying claims are made as to qualities of plasticity or workability, all are equally suitable for general building purposes. In the case of finishing coats for plasterwork, however, preference is given to that lime which works most easily under the trowel.

The chemical change which takes place during the calcination or "burning" of the limestone destroys the bond between the calcium oxide or magnesium oxide and the carbon dioxide. Under the action of heat, the carbon dioxide together with any moisture contained in the stone is expelled, leaving calcium oxide or "quicklime." This lime contains small percentages of impurities which were present in the original stone and which it is impossible to remove in the calcination process. These impurities are silica, alumina, iron oxide, etc. They are not injurious to masonry mortar or to plaster, provided they are present in proportions which do not exceed the limit set by the Standard Specifications of the American Society for Testing Materials.[2]

Two general types of kilns are used for calcining or "burning" limestone—the shaft kiln and the rotary kiln. A third type of kiln, known as an "intermittent" kiln, which was in general use some years ago, has now become obsolete and will be found in only the smallest and most antiquated lime plants.

The shaft kilns now in general use are of the continuous type. They vary somewhat in details of construction but, in general, consist of a vertical shaft, lined with refractory brick, into which the raw limestone is charged at

[1] Tentative Definitions of Terms Relating to Lime. Serial Designation: C 51-24T, 1926, American Society for Testing Materials Tentative Standards.

[2] Complete specifications for quicklime for structural purposes have been issued by the A.S.T.M. as Standard Specifications for Quicklime for Structural Purposes. Serial Designation: C 5-26.

the top, and a cooling chamber at the base from which the calcined quicklime is removed. The cross-section of the kiln shaft is usually circular or elliptical. The fire grates are located at the side of the kiln at the base of the calcining shaft and just above the cooling chamber. A brick bridge wall between the grates and the shaft of the kiln prevents the coal and clinker from mixing with the lime. The hot gases of combustion, obtained from the burning of the coal on the fire grates,[1] pass up through the shaft of the kiln and bring about the chemical change above described. As the quicklime is removed from the bottom of the cooling chamber, fresh limestone is charged into the top of the kiln, so the process continues without interruption.

Rotary kilns as used for the calcination or "burning" of limestone are of the same type as those used for the manufacture of Portland cement. They consist essentially of a horizontal rotating cylinder lined with fire brick. Raw limestone is fed into one end of the kiln; fuel for calcination, in the form of either producer gas or pulverized coal, is charged at the opposite end. Raw limestone moving through the kiln meets an increasing temperature as it proceeds and is discharged as quicklime from the end of the kiln opposite to that into which the raw limestone was charged.

73. Slaking Quicklime. The standard specifications for quicklime for structural purposes issued by the A.S.T.M.[2] give, in the form of an appendix, the following information concerning the slaking of quicklime:

Quicklime can never be used as such for structural purposes; it must always be slaked first. Since the method of slaking is an important factor in determining the quality of the finished product, the following directions are given, not as a part of the specifications, but as information for the further protection of the purchaser:

1. (*a*) **Introduction.**—Different kinds of lime vary considerably in the way in which they behave with water. A little supervision over the operation of slaking will amply pay for itself by insuring the production of the greatest possible quantity and the best possible quality of putty. To find out how to slake a new lot of lime, it is safest to try a little of it and see how it works. Since different lots of the same brand of lime vary somewhat, and since the weather conditions at the time have decided influence, it is wise to try a sample from each lot used, whether familiar with the brand or not.

(*b*) **Classification of Limes.**—In a bucket, put two or three lumps of lime about the size of one's fist or, in the case of granular lime, an equivalent amount. Add enough water just barely to cover the lime, and note how long it takes for slaking to begin. Slaking has begun when pieces split off from the lumps or when the lumps crumble. Water of the same temperature should be used for test and field practice.

If slaking begins in less than 5 min., the lime is quick slaking; from 5 to 30 min., medium slaking; over 30 min., slow slaking.

(*c*) **Directions for Slaking.**—For quick-slaking lime, always add the lime to the water, not the water to the lime. Have enough water at first to cover all the lime completely. Have a plentiful supply of water available for immediate use—a hose throwing a good stream, if possible. Watch the lime constantly. At the slightest appearance of escaping steam, hoe thoroughly and quickly, and add enough water to stop the steaming. Do not be afraid of using too much water with this kind of lime.

For medium-slaking lime, add the water to the lime. Add enough water so that the lime is about half submerged. Hoe occasionally if steam starts to escape. Add a little water now and then if necessary to prevent the putty from becoming dry and crumbly. Be careful not to add any more water than required, and not too much at a time.

For slow-slaking lime, add enough water to the lime to moisten it thoroughly. Let it stand until the reaction has started. Cautiously add more water, a little at a time, taking care that the mass is not cooled by the fresh water. Do not hoe until the slaking is practically complete. If the weather is very cold, it is preferable to use hot water, but if this is not available, the mortar box may be covered in some way to keep the heat in.

2. (*a*) **White Coat.**—After the action has ceased, run off the putty through a No. 10 sieve and store for a minimum of 2 weeks.

(*b*) **Base Coats.**—After the action has ceased, run off the putty through a No. 8 sieve. Add sand up to equal parts by weight, all of the hair required, and store for a minimum of 2 weeks.[3]

(*c*) **Mason's Mortar.**—After the action has ceased, add part or all of the sand required, and store for a minimum of 24 hr.

74. Hydrated Lime.—Hydrated lime is defined by the A.S.T.M.[4] as follows:

[1] In some cases, producer gas may be used as a source of fuel in the place of coal.

[2] Standard Specifications for Quicklime for Structural Purposes. Serial Designation: C 5-26, American Society for Testing Materials.

[3] Some plasterers maintain that the slaked lime, when thoroughly screened, gives better results in base coats if promptly used with its own "lime water" than if allowed to age, because through evaporation, it loses some of its potency when it must then be retempered with fresh water. Ageing, on the other hand, it is claimed, permits moisture to come in contact with all particles of the oxide and offers greater assurance of thoroughly and completely slaking.

[4] Standard Specifications for Hydrated Lime for Structural Purposes. Serial Designation: C 6-24, American Society for Testing Materials.

Hydrated Lime. A dry powder obtained by treating quicklime with water enough to satisfy its chemical affinity under the conditions of its hydration.

NOTE.—It consists essentially of calcium hydroxide or a mixture of calcium hydroxide and magnesium oxide and magnesium hydroxide.

Hydrated lime is prepared at the mill by machinery especially designed for the purpose. The principle of the process is intimately to mix quicklime with a predetermined quantity of water sufficient to satisfy the chemical affinity for water and produce a thoroughly dry powder. In the case of a chemically pure high-calcium quicklime, 56 parts of calcium oxide would combine with 18 parts of water by weight, resulting in 74 parts of calcium hydroxide or hydrated lime.

Hydrated lime is of two distinct classes known as "masons' hydrate" and as "white finishing hydrate." The major difference between these two classes of hydrated lime is in plasticity or workability, the white finishing hydrate being much more plastic and easier working than is the masons' hydrate. Complete specifications for both classes of hydrated lime have been issued by the A.S.T.M. as Standard Specifications for Hydrated Lime for Structural Purposes. Serial Designation: C 6-24.

Hydrated lime is packed for shipment in paper sacks containing 50 lb. and is ready for use. It is not necessary to slake and age hydrated lime, but it is customary to require it to be soaked for 24 hours before mixing with ingredients, to be entirely sure that all particles are thoroughly hydrated with no lime oxide remaining.

75. Uses of Lime Plaster and Mortar.—Lime products (lump and hydrated lime) are used for various purposes in building construction. The principal uses are as follows:

Scratch- and brown-coat interior plastering.
Finish-coat interior plastering.
Exterior stucco.
Mortar for brick and stone masonry.
As a flux for concrete.

76. Lime Mortar.—The hardening of lime mortar consists partly in the crystallization of lime hydrate and partly in reconverting this into calcium carbonate through exposure to carbon dioxide in the air. It is evident from this that ventilation is highly desirable for prompt hardening of all lime mortars or plasters.

To ensure safety of life and property it is necessary that mortar be of sufficient strength to safely carry all loads imposed on it. In concrete and steel structures the safety of the building is amply protected by a factor of safety of four, or the working load is figured as one-fourth the average ultimate load. As mortar is no more susceptible to the vicissitudes of workmanship than is concrete, the same factor of safety should be amply sufficient in designing mortars.

In 1915, Professor MacGregor made tests at Columbia University to determine the strength of brickwork laid up with various mortar. The results are shown in the following table:

ULTIMATE RESISTANCES OF 8 × 8 × 84-IN. BRICK PIERS LAID UP WITH DIFFERENT MORTARS SHOWN

	1	2	3	4	5	6	7
Mortar mix	100 pounds C .... 300 pounds S	90 pounds C 4 pounds HL 300 pounds S	85 pounds C 6 pounds HL 300 pounds S	75 pounds C 10 pounds HL 300 pounds S	50 pounds C 20 pounds HL 300 pounds S	25 pounds C 30 pounds HL 300 pounds S	40 pounds HL 300 pounds S
Crushed at:							
7 days	2630	3080	2890	3120	2760	1945	1535
28 days	2840	3170	3230	3470	3100	2370	1870
3 mo.	2840	4435	4300	4170	3820	2720	1950

C—Portland cement. HL—Hydrated lime. S—Sand.

The Building Code Committee of the U. S. Department of Commerce in March, 1926, prepared a compilation of data on compression tests on brick masonry. The strengths of straight lime mortar, scattered throughout these tests, show results 95 % of which vary from a maximum of 2000 lb. per sq. in. to a minimum of approximately 500 lb. per sq. in. Taking the average minimum strength of 500 lb. per sq. in. and applying a factor of safety of 4, a safe working load of 125 lb. per sq. in. is obtained for straight lime mortar. This is an entirely logical code strength and is developed along legitimate engineering lines.

It is a well-known fact that, in general, designers do not figure the stresses on brickwork, and for this reason little consideration has been given to its economical features. In order to form a more careful consideration of masonry, the Department of Commerce Building Code Committee, as the result of the various tests before referred to and of others more recently conducted at the Bureau of Standards, saw fit to include a clause in its code which permits a load of 135 lb. per sq. in. on straight lime mortar when the stresses are calculated.

For straight lime mortar the following approximate quantities are recommended:

1:2	lump lime mortar	1¾ bbl. lump lime and ½ cu. yd. of sand.
1:2½	lump lime mortar	1⅜ bbl. lump lime and ½ cu. yd. of sand.
1:3	lump lime mortar	1⅛ bbl. lump lime and ½ cu. yd. of sand.
1:2	hydrated lime mortar	6½ sacks hydrated lime and ½ cu. yd. of sand.
1:2½	hydrated lime mortar	5¾ sacks of hydrated lime and ½ cu. yd. of sand.
1:3	hydrated lime mortar	5 sacks of hydrated lime and ½ cu. yd. of sand.

77. Use of Lime Products in Cement Mortar.—The use of lime products in cement mortar produces the following results:

1. Lime introduces into the mortar a high degree of plasticity or workability so the mortar can be easily spread, thus providing a more uniform bedding for the bricks.

2. The so-called suction of the brick affects a cement-lime mortar to a much less degree than it does a straight cement mortar. The use of lime is said to aid in the retention of moisture in the mortar for the more nearly complete hydration of the cement in the mixture, thus causing the cement to work at higher efficiency. This point is possibly brought out in the above table by the comparison of mortar No. 5 with mortar No. 1. The economical feature in this test is that a mortar composed of 20 lb. of hydrated lime, 50 lb. of Portland cement, (a total of 70 lb. of cement material) and 300 lb. sand, developed a strength approximately 1000 lb. per sq. in. stronger than a mortar composed of 100 lb. of Portland cement and 300 lb. sand.

In connection with the use of lime in concrete, a certain degree of skepticism is often expressed by engineers and contractors as to the real advantage to be gained by the use of an admixture in concrete. Questions as to the relative strength-deterioration, absorption, permeability, density, and workability of concrete with and without an admixture often arise. The experience of many has been, however, that lime gives added flowability to the mass and in properly proportioned quantities is advantageous as an admixture in Portland cement concrete.

The Committee on Building Code Requirements for Lime in its *Report* submitted to the Building Officials Conference in April, 1926, a report which was accepted and ordered printed in the *Proceedings* for a year before final consideration, included this recommendation:

The following maximum admixture of hydrated lime in concrete shall be permitted in all classes of concrete construction except where the concrete is deposited under water:

Maximum Addition

Mix	Pounds of hydrated lime per sack of cement
1:1½:3	6
1:2:4	10
1:2½:5	12
1:3:6	16

The quantities of Portland cement, sand, and coarse aggregate shall not be altered in any way, the hydrated lime being added as an additional ingredient.

In hand-mixed concrete, all materials shall be thoroughly mixed while dry.

78. Proportions of Materials for Lime Plaster.—The following proportions of materials in preparing one ton of lime plaster have been found to produce excellent results:

For Wood Lath Surfaces

Scratch Coat.—11¼ cu. ft. hydrated lime (9 sacks) or 9½ cu. ft. lime putty, 15½ cu. ft. sand, and 3 lb. hair or fiber.

Brown Coat.—9 cu. ft. hydrated lime (7 sacks) or 7¾ cu. ft. lime putty, and 16½ cu. ft. sand.

White Finish.—Finishing hydrated lime, or freshly burned quick lime, properly slaked, gaged with calcined gypsum.

Sand Float Finish.—To each cubic foot of lime paste used, add and thoroughly mix one cubic foot of sand.

Metal Lath Surfaces

Scratch Coat:

8 cu. ft. hyd. lime (6¼ sacks)		7 cu. ft. lime putty
1½ cu. ft. Portland cement		1¼ cu. ft. Portland cement
15½ cu. ft. sand	or	15½ cu. ft. sand
3 lb. hair or fiber		3 lb. hair or fiber

The Portland cement should be separately mixed with its proportion of sand and added to the mixture just previous to applying the plaster.

Brown Coat:

9 cu. ft. hydrated lime (7 sacks)	or	7¾ cu. ft. lime putty
16 cu. ft. sand		16½ cu. ft. sand

Finish Coat:
Same as prescribed for application to wood lath.

MASONRY SURFACES

Scratch Coat.—9 cu. ft. hydrated lime (7 sacks) or 7¾ cu. ft. lime putty and 16½ cu. ft. sand.
Brown Coat.—Same proportions as for scratch coat.
Finish Coat.—Same as prescribed for application on wood lath.

CONCRETE SURFACES

15 cu. ft. hyd. lime (12 sacks) or 12¾ cu. ft. lime putty, 1 cu. ft. sand, and 250 lb. calcined gypsum. No more than 1 coat of plaster on concrete surfaces is recommended.

79. Plastering Specifications.—The Contracting Plasterers' International Association has adopted a Standard Specification for Plastering. The following is the full text of the current edition except for those brief portions referring to other than lime plaster.

Grounds.—All grounds for various classes of work to be as follows, unless expressly specified to the contrary:

Grounds	Inches
For two-coat lath work	⅞
For three-coat lath work	1
For three-coat metal lath work	⅝
For three-coat metal lath work on ½-in. iron furring	1⅛
For three-coat metal lath work on 1-in. iron furring	1⅝
For two-coat work on brick or tile	⅝

Where metal lath is spoken of it applies to all wire or metal lath.

Lime.—All lime to be fresh-burned plasterers' lump lime, or standard plasterers' hydrated lime.

Sand.—All sand to be clean, sharp sand free from loam.

Wood Lath.—All wood lath to be Grade 1 lath 1½ in. wide.

Nails.—To be 3-d. fine, No. 16 gage wire nails.

Wire or Metal Lath.—All wire lath to be No. 18 gage 0.0475 ⅜-in. mesh painted-wire lath, weighing 3.3 lb. per sq. yd., or No. 24 gage metal lath painted, weighing no less than 3.4 lb. per sq. yd.

Stucco—All stucco to be fresh.

Hair to be well-whipped cattle hair.

Fiber to be long vegetable fiber, well whipped.

Metal Corner Beads.—To be properly galvanized.

Lathing.—All wood lath to be nailed to each stud joist or bearing, with joints broken, not over seven laths to a break, no diagonal or vertical lathing allowed, a full ⅜-in. key to be left for lime and mortar.

Lime Mortar.—To be composed of clean, coarse sand, fresh lump lime, and hair or fiber in proper proportions and to be well slaked and protected.

Putty.—Fresh-burned lump lime to be run off in a tight putty box, thoroughly slaked and screened through a fine putty screen. Hydrated lime, when used, to be soaked with water in a tight box for not less than 24 hours.

Hard Finish.—To be composed of cold lime putty, plaster of Paris, and sand to be well troweled to a smooth, even surface, free from blisters, checks, and other imperfections.

Sand Finish.—All float sand finish to be composed of lime putty and sand to be water floated with a float to an even granular or sand surface.

Scratch Coat.—All scratch coating to be well laid on and surface covered with a full coat which is to be well scratched, to be well undercut for the brown coat, all lime-mortar scratch coating to be dry before applying the brown coat.

Brown Coat.—All brown coating to be well applied, allowing only sufficient space for the finish coat, brown coat to be rodded and screeded with all angles straight and true.

Wire or Metal Lath.—Shall be lapped at each joint or seam and shall be stapled every 6 in. with blue or galvanized staples.

Band-iron Furring.—As specified, to be ½, ¾ or 1 in. crimped and painted band iron of No. 22 gage metal, such furring to be stapled to bearing and the wire or metal lath to be applied and stapled over such band-iron furring.

Suspended Ceilings.—To be constructed of 1½- or 2-in. flat bar angles, tees, or channels, as may be called for, such principals shall be spaced not more than 4 ft. 0 in. on centers hung with flat-bar or ¼ in. mild-steel rod hangers, 4 ft. 0 in. on centers, securely fastened with approved clips to the structural framing or through the floor construction; in the event these hangers go through the floor construction, they shall be provided with a 6-in. channel or flat-bar anchor, no hanger shall be attached to or supported from the bottom flange of a tile arch. The flat-bar, angle, tee, or channel runners shall be cross-furred with ¾-in. steel channels 12 in. on centers, with approved mild-steel rod clips, or a double tie of not less than No. 14 gage annealed galvanized wire. The center construction to be

lathed with No. 18 gage wire lath or No. 24 gage metal lath of the quality and weight heretofore called for. Such lath to be placed with lapped joints and tied to cross-furring every 6 in. with soft annealed No. 18 gage galvanized tie wire, all hangers, principals, and cross-furrings to be coated with paints.

Furring.—All false beam or cornice furring to be constructed of ¾-in. channel or 1-in. flat-bar brackets not over 2 ft. 0 in. apart lined out with intermediate furring supports and anchored or toggle bolted into the construction to be made to conform to the design so as to allow for a minimum of plaster, such brackets to be covered with No. 18 gage wire or No. 24 gage metal painted lath secured with No. 18 gage galvanized wire, such furring to conform to the latest and best practice as to durability of construction.

Cornice Work.—All moulded beams and cornices will be screeded and run in place with moulds, with true lines and accurate mitres.

Ornamental Work.—All patterns to be turned out by skilled mechanics with true and accurate lines. All models for ornamental work shall be satisfactory to the architect.

Casts.—All casts to be well made, the contractor to supply a sufficient number to meet the requirements of the job; all casts to be made in line, well and truly undercut and free from warps and other irregularities supplying all necessary shrinkers and stretchers.

Concrete Walls and Columns.—All work on concrete walls and columns shall have such concrete well brushed with steel brushes, and such concrete shall then be covered with a light bond coat of cement as a bonding coat for the finish coat.

Concrete Ceilings.—Shall be first washed with a solution of muriatic acid and water; such ceilings shall then be plastered as above.

Painted Walls.—Walls that are to be coated with asphaltum waterproofing compounds should first be scratch coated, then browned or finished.

Patching of Plasters.— All patching of plaster damaged by mechanics shall be paid for.

Scaffold.—This contractor shall supply all necessary tools, scaffold, and other appliances necessary to fulfil the requirements of the job, all scaffolding to be erected and maintained in accordance with the laws of the state relating to scaffolds.

Supplementary

This specification is intended to aid architects, engineers, and others interested in the fundamentals requisite for good work and is a coordination of the experience of practical men.

The following additional suggestions are offered:

Wood Lath.—In the Southwestern states yellow pine lath are used.

In the Pacific Coast regions pine and fir lath are used.

In the Eastern states, pine and cypress lath are used.

In the central West, mixed lath composed of hard pine and hemlock are used.

Due to the changing building conditions, this association recommends the use of wire or metal lath in all buildings of ordinary construction; its use results in slow-burning monolithic construction at a reasonable cost, which cannot appreciably affect income returns on such buildings, while its use adds permanency, safety, and the minimum of repairs to such buildings.

STUCCO

By W. E. Hart

Stucco, in one form or another, has been employed as an exterior treatment for dwellings since the early Christian era. A study of early history shows that the Aztec and the early Egyptian employed mud or clay mixed with lime and plastered on reeds or small branches of trees for the exterior of their huts. The later Egyptian and the Greek became more proficient in the application of this crude material and at the same time developed a plaster composed of limes and volcanic ash. This new composition gave greater life and withstood the ravages of time much better than the old clays. Examples still exist in the ruins of Greece and Rome of plaster of this character. In many cases, bright colors were added to the mixture, thus accentuating details. With the advent of modern plastic materials, such as Portland cement and the lime stuccoes, it has been possible to build permanence into the structure which was impossible under the practice of the ancients.

Stucco has come into general use in this country as an exterior finish for residences and many types of other structures. One reason for this has been the adaptability of a plastic material and the unusual effects that can be obtained with it as a decorative medium. Today, color and texture are items of interest in the exterior treatment of homes. The home builder is not satisfied with merely finishing his home with a color and texture that are appropriate to the design; but he demands proper planting and landscaping so as to set off his dwelling to the greatest degree. It may, therefore, be expected that in the years to come a great deal of stucco

will be employed in our national life. The craftsman is being educated in the proper application of stucco. The architect is interested in detailing his modest dwellings in a material that so artistically represents his thoughts that the public is charmed by the results of the labors of these two crafts.

Many industries have coöperated with the Bureau of Standards in the preparation of tests and investigations. As a result of this experimental work, standards have been set up for the quantities and kinds of material and the proper kinds of construction upon which stucco can be applied. Exposure tests have been conducted at the Bureau of Standards since 1909. These tests have established a definite relationship between methods of construction and the application of plastic materials. These tests by the Bureau are now standards of the American Concrete Institute and are embodied in the recommendations of the Portland Cement Association, The Associated Metal Lath Manufacturers, and many other agencies.

80. The Importance of Proper Design for Stucco Construction.—Successful stucco work depends, in a large measure, upon the proper design of the structure. If the base is not rigid, the additional stress placed in the stucco slab may cause it to crack, even though the best of construction has been used in the slab itself. This thin 1-in. slab should not be expected to stand alone or in any way strengthen the structure upon which it is placed. It is essential, therefore, to design the walls, regardless of material, sufficiently rigid to resist normal wind pressures or movements. The stucco coat should merely serve as an exterior treatment or decorative finish.

Stucco bases divide themselves into three general classes, as follows: (1) monolithic concrete wall; (2) masonry wall; (3) frame or timber wall.

Each of these classes involve a somewhat different technic and are, therefore, discussed under three separate headings.

1. *Monolithic Concrete Walls.*—A new practice has been introduced to avoid difficulties experienced in the past in the application of cement mortars to monolithic concrete walls. This process involves the application on the forms, prior to the placing of the concrete in the wall, of a material that retards the hardening of the cement upon the surface of the concrete. After the concrete has hardened and the forms are removed, the wall is wire brushed, thus revealing the coarse aggregate in the concrete. After the concrete has dried out for a period of several months, the walls are given a scratch coat of the standard stucco mortar. Under this method, it is possible to obtain a mechanical as well as a suction bond for the scratch coat.

Another method used extensively on the Pacific Coast is to wire brush the wall immediately upon removing the forms. As soon as the wall has dried out, it is dashed with a mixture of 1 part of cement to 2 parts of sand, mixed to a creamy consistency. This dash coat should be permitted to cure and dry out for a period of 4 to 5 days before the application of the brown coat. The wall is then ready to receive the finish decoration as desired by the architect.

2. *Masonry Walls.*—Walls made of concrete block, brick, hollow tile, and similar materials should be rigid and constructed upon solid footings. The surface upon which the stucco is to be applied should be clean, free from all dirt, dust, or loose particles, and preferably of a rough texture. All mortar joints should be cut back from the surface of the wall. Where clay tile are used, they should be hard burned with dovetail or heavy, ragged scoring. Clay-brick walls should be composed of a rough, hard-burned clay brick and, if painted or waterproofed, should be covered with a reinforcing fabric before the application of the first coat of stucco.

3. *Frame or Timber Walls.*—The studs for timber walls should not exceed 16 in. on centers. Studding should run from the foundation to the rafters without intervening horizontal members. The studs should be tied together below the second-floor joist with a 1 × 4 board let into the inner face of the studs. If open construction is used without sheathing, the studs should not be spaced to exceed 12 in. The corners for all walls should be braced to ensure the necessary rigidity of the structure. Bridging of the studs with 2 × 4 braces should be placed at least once in every story height. Where sheathing boards are used, they should be not less than 6 in. nor more than 8 in. in width, dressed to a uniform thickness, and laid horizontally. Diagonal sheathing should not be used under any condition, as this construction will tend to develop diagonal cracks in the stucco. Over the sheathing shall be laid horizontally, beginning at the bottom, any standard asphalt-saturated roofing felt weighing not less than 15 lb. per square, the bottom layer lapping the baseboards and each strip lapping the strip below at least 2 in. This construction prepares the wall to receive the reinforcement. A specification for this reinforcement is given below:

"Reinforcement shall consist of expanded metal cut from sheets not less than 20 gage in thickness with openings not less than ¾ × 2 in. nor greater than 1½ × 4 in. in size, the fabric to weigh not less than 1.8 lb. per sq. yd., or wire fabric composed of wires not smaller than 18 gage used with openings not less than ¾ in. square or with wires not smaller than 14 gage used with openings not greater than 2 in. square."

"Reinforcement shall be placed horizontally, fastened with approved furring devices not more than 8 in. apart over the surface. Vertical laps shall occur at supports, horizontal joints being lapped and tightly laced with 18 gage annealed wire. The sheets shall be returned around corners at least 4 in. in sheathed construction and 16 in. in open construction. Corner beads shall not be used."

81. Reinforcement.—Failures that have existed in many stucco walls in the past have been largely due to the fact that interior methods and construction have been employed on the exterior rather than developing a type of construction that is suitable for exterior exposure. The specification above referred to anticipates the use of a type of stucco mesh that builds up a scratch or first coat ½ in. thick, followed by a second or brown coat of like thickness. In the first place, reinforcing mesh is nailed and tied securely to the wall so that it functions as one unit, thus preventing vertical or horizontal cracks. With a scratch coat completely embedded behind the metal, a base coat for the stucco is built up which has a rigidity, strength, and permanence that does not exist in the older type of construction.

Many of the failures in the old work were primarily due to the fact that the scratch coat was not forced through the metal lath, thus failing to protect the metal or build up a scratch coat of sufficient strength to carry the load of the second and finish coats. It is essential, therefore, to consider carefully the placing of the reinforcement and the first coat where frame walls are being stuccoed.

82. General Provisions.—The design of the walls should be such as to prevent concentrated flows of water over the surface of the stucco. Wherever the stucco joins the structures, or at the top of cornices or coppings, the walls should be properly flashed to prevent water from getting in behind the stucco. All moldings and ornaments should be made to run the water off quickly. All hangers, drips, and fastenings should be in place before the stucco is applied. Chimneys to be stuccoed should first be covered with a reinforcing fabric, properly placed and supported to the surface. The use of reinforcement, in this case, is a precaution taken to prevent cracking due to the differences in temperature between the wall of the chimney and the exterior surface of the stucco.

The materials for a Portland cement stucco consist of a standard Portland cement sand, graded from 0 to ¼ in., and clean water. To this mixture may be added hydrated lime in an amount equal to one-fifth of the volume of the cement. Lime is added to aid in the proper application of the stucco and not as a waterproofing agent. Stuccoes, made under the procedure indicated in this chapter, will be of such density that they will shed water with little or no absorption.

83. Proportions.—The life of a stucco, or its ability to resist weathering, depends upon two qualities. First, the proper application of the material to the wall and, second, the proportions, or combination, of materials that make the stucco.

As a result of the tests carried out at the Bureau of Standards, a satisfactory mixture is one composed of 1 part of cement to 3 parts of sand, to which may be added hydrated lime equaling 10% of the weight of cement. These materials are mixed dry until the mix is uniform in color. Water is then added to give the required plasticity and the whole mix re-mixed until the mortar is uniform in consistency. The exact amount of water required depends entirely upon the kind of wall that is to receive the mortar and the ability of the craftsman to place the mortar. Richer mixes than the one above specified may tend to develop craze cracks. A mixture leaner than 1:3 will be too harsh for the craftsman to apply properly. The recommended mixture represents an average that is easily placed and if cured during the first 2 days after application should develop little or no craze cracks. The mixture above specified should apply for all three coats. It may be necessary, in some cases, to change the grading of the sand and the proportion of cement to sand for the finish coat. If a coarse texture is required, a 1:3 mix with 10% of lime will be entirely satisfactory. If, however, a smooth finish is desired, then the ¼-in. material should be removed from the sand and the mixture adjusted so that the relationship of cement to sand is approximately 1:2½. This mortar is applied thin to the brown coat by forcing it into the pores with considerable pressure on the trowel. Plasterers usually call this a thin, tight coat.

A convenient specification for proportioning is given below:

"Mortar for both scratch and brown coats shall be mixed in the proportions of five sacks of Portland cement, one 50-lb. sack of hydrated lime, and 16 cu. ft. of sand. The finish coat, if not a prepared Portland cement stucco, shall be of like proportions to those used in the previous coats, with such additions of mineral coloring pigments as necessary, but in quantities not to exceed 6% of the volume of the cement used."

"Dry mixing of ingredients shall be carried on until the color is uniform; wet mixing until the consistency is uniform. It is positively essential that a definite system be used which shall produce uniform mixes for scratch and brown coats. The quantity of water shall be determined by trial and thereafter used in the proper proportions."

84. Application.—The procedure to follow in the application of the three coats of stucco is as follows:

After the scratch or first coat has been applied to the wall, regardless of the type of base, it should be lightly scored, and as soon as it has hardened sufficiently to prevent washing, it should be sprinkled and kept wet for a

period of at least 2 days. The wall should then dry out slowly for a period of at least 5 days. Under no condition should the brown or second coat be applied until after the walls are thoroughly dry.

The brown coat is then applied in the same manner as the scratch coat to a thickness of not less than ½ in. This wall should be cured and permitted to dry out slowly, as described under the application of the scratch coat. After this coat has become thoroughly dry, it is then ready to receive the finish or decorative coat. The time elapsing between the placing of the scratch and brown coat permits all shrinkage and loading cracks to appear in the scratch coat, so that when the brown coat is applied, these cracks are completely buried. With proper suction in the scratch coat, the brown coat is knitted into the scratch coat to such an extent that the bond cannot be broken nor will it permit the passage of moisture into the structure itself.

The methods and tools for making the finish coat depends entirely upon the texture to be used and the effects to be produced. The application of this coat is a distinct art in itself, and the plastering contractor should endeavor to use only experienced workmen. Many variations of color and texture are possible, and the limitations of artistic effects are only the limitations of the craftsman himself. The texture should be a frank expression of the technique of application. A variation of pleasing appearance is given by producing a texture of smooth surface over a rougher textured base. Combinations of texture and color variations can contribute their full measure to the beauty of an architectural conception.

85. Color.—The generous use of color is apparent in the newer stuccoed effects. There has been a decisive change in the past few years taking place in the design and in the color treatment of American homes. These color effects are chiefly secured by the addition of mineral pigments which are mixed by grinding together the cementing material, sand, and color. Other effects are produced by the use of colored aggregates which are exposed by brushing and acid treatment after the stucco has hardened. The ability of any color selected to harmonize with the texture of the architectural style and the natural setting of the house is of primary importance. The ultimate artistry of a design and its most successful rendition can be accompanied only when the three factors of appearance—form, texture, and color—are artistically balanced.

Mineral pigments should not be mixed on the job when it is possible to purchase reliably prepared, machine-mixed materials. If prepared stuccoes are not available, only the best mineral coloring pigments that are guaranteed by the manufacturers to retain their color when mixed with cement should be used. The finer the coloring materials are ground and the better they are distributed throughout the mortar the greater is their ability to impart their full color. Tests should be made by mixing small pats of the standard mortars with the proper amount of color added to determine the exact shade to be used for the stucco. These pats should be permitted to dry slowly for 4 or 5 days. Wet mortars are darker than dry mortars. Water is a factor in color. Coloring matter, in general, should not exceed 6 % of the weight of the cement. It is impossible to give a definite formula for the amount of color to be used for any given job. It is best to experiment by mixing known quantities of color with the cement and sand and permitting these colors to harden and dry out as above described.

A general guide to the selection of coloring materials to obtain various tints in stucco follows:

Reds and pinks	red oxide of iron
Yellows and buffs	yellow oxide of iron
Greens	chromium oxide
Browns	brown oxide of iron
Blues	ultramarine blue
Grays or slate effects	manganese black, drop black, or Germantown lampblack.

It is recommended that, wherever possible, a prepared stucco be used. The principle underlying the preparation, proportioning, and mixing of colors with Portland cement can easily be understood by the average plasterer. However, the mixing of delicate shades on the job, without accurate measuring devices, may tend to develop mottled and uncertain results in the finished work. Where the materials are mixed on the job, a structure may start out with one color and end up with another. It is advisable, therefore, to use a material that is prepared under plant supervision, having the advantage of factory-measured and -proportioned materials, machine mixing, and the grinding of the color pigment with the cement. It is also essential for the plasterer to follow the manufacturer's directions very carefully. Many stucco jobs have been ruined by the plasterer's adding extraneous materials, which has resulted in bad spots, poor color effects, and general dissatisfaction on the part of the owner.

86. Overcoating Old Houses.—Overcoating is a term generally applied to the method of using Portland cement stucco as a covering for the exterior surface of old houses. The structural frame of the dwelling may be in a perfect condition, but the architecture and the exterior of the building are exceedingly out of date. The problem, therefore, of applying a stucco coat to the house may be one of not only saving the structure but also stabilizing the real value of the house.

The procedure to follow in placing an overcoat on an old job is as follows: All siding should be securely re-nailed to the studding and then covered with a 15-lb. asphalt roofing felt. The

same type of reinforcement should be used as on a new job. This reinformcent should be furred out ½ in. thus permitting the building up of a scratch coat of sufficient rigidity to support the brown and finish coats. From this point on, the procedure is identical to that recommended for new work.

87. Other Types of Stucco.—Aside from Portland cement stucco, which is the type most widely used, there are two others which deserve mention.

One of these is the lime stucco of earlier days, of which many splendid examples are still in existence. The question arises, Why were these lime stuccoes almost wholly abandoned in favor of Portland cement, when their quality and durability are evidenced by the fact that some of them have endured for more than a century? From examination of some of the well-known lime stuccoes of Germantown, Pa., and elsewhere, the writer is of the opinion that the conditions under which these stuccoes were built are conditions of the past (houses with 18-in. stone walls, lime slaked 12 months before use, mortar applied in thin coats, and each left to harden for an indefinite time); these were conditions highly favorable to lime stucco, but they no longer obtain. It is true that there are satisfactory stuccoes of the present period in which varying proportions of lime and cement have been used, many of them no doubt containing more lime than cement, but so many failures may be traced directly to faulty combinations of these materials, and so much evidence has accumulated to demonstrate the superiority and greater reliability of Portland cement, that mixtures containing more than 20 to 25% of lime by volume should be avoided in modern practice.

Within the last 8 yr., a new type of stucco has been marketed as a proprietary product by a number of competing manufacturers. This material, commonly known as "magnesite stucco," is a mixture of magnesium oxide, sand, asbestos, and other fillers and, when gaged with a solution of magnesium chloride, forms a plastic mortar which develops a strength comparable with that of Portland cement mortar. As a stucco it has certain advantages over Portland cement stucco, the chief of which are greater plasticity and the fact that it can be applied without injury in freezing weather. On the other hand, its chief disadvantages are intrinsically high cost, low resistance to the action of water and continued dampness, its tendency to corrode metal lath, and the present necessity for obtaining all materials and ingredients from the manufacturers. There seems to be a lack of understanding on the part of the plastering craft of a rather complicated method of mixing and applying this material. As a result of this misunderstanding, many failures exist. The lack of complete information regarding the properties and characteristics of the cementing materials and the lack of specifications which will ensure the quality of the finished product are the chief reasons for a conservative attitude toward magnesite stucco at the present time.

GYPSUM AND GYPSUM PRODUCTS

By George A. Hool

Pure gypsum is hydrous calcium sulphate,—*i.e.*, calcium sulphate carrying water of crystallization. Its chemical formula is $CaSO_4 + 2H_2O$.

88. Gypsum Plasters.—Where gypsum is heated to a temperature between 250 and 400 deg. F., it loses about three-fourths of its combined water and the calcined product is known commercially as *plaster of Paris*. This product, when finely powdered and mixed with water, takes up in combination as much water as it lost through calcination and becomes rigid, or "set," through recrystallization.

As found in nature, gypsum contains impurities, such as SiO_2, Al_2O_3 and Fe_2O_3, $CaCO_3$ and $MgCO_3$. If these impurities or substances such as fiber, added for the purpose, are present in the calcined product, they retard setting; and such gypsum plasters are termed "slow-setting." *Cement plasters*, so called, are gypsum plasters and may be either slow or fast setting.

By calcining gypsum above 900 deg. F., a very hard *flooring plaster* is produced, which sets very slowly. *Keene's cement* is obtained by calcining pure gypsum at red heat, immersing it in an alum bath, then drying and calcining it again. *Mack's cement* is dehydrated gypsum mixed with 0.4% of sodium or potassium sulphate. This plaster takes a quick, hard and durable set and is used for floorings or for stuccoing on walls and ceilings.

89. Classification of Calcined Gypsum and Gypsum Plasters.—The A.S.T.M. Standard Specifications for gypsum (Serial Designation: C 22-25) set forth in detail the following materials and standards:

Testing.—The chemical and physical properties of gypsum shall be determined in accordance with the Standard Methods of Testing Gypsum and Gypsum Products (Serial Designation: C 26) of the American Society for Testing Materials.

Definition.—(*a*) Pure gypsum is calcium sulfate combined in crystalline form with 2 molecules of water.

(*b*) Its chemical formula is $CaSO_4 \cdot 2H_2O$.

(*c*) No material may be considered gypsum within the meaning of these specifications which contains less than 64.5 % by weight of $CaSO_4 \cdot 2H_2O$.

Forms and Sizes.—Gypsum may be in any of the following forms and sizes:

(*a*) Run-of-mine Gypsum.—The form in which it comes from the mine or quarry.

(*b*) Crushed Gypsum.—Run-of-mine gypsum further reduced so that all of it will pass a 3-in. (76-mm.) ring, and not more than 25 % shall pass a No. 100 sieve.

(*c*) Sized Gypsum.—Shall all pass a 1½-in. (38-mm.) ring, and not more than 10 % shall pass a ¼-in. sieve.

(*d*) Ground Gypsum.—Gypsum further reduced for specific uses. Ground gypsum may be in any of the following standard forms:

No. 1.—This material shall all pass a No. 14 sieve, and not less than 85 % of it shall pass a No. 100 sieve.

No. 2.—This material shall all pass a No. 14 sieve, and not less than 60 nor more than 85 % of it shall pass a No. 100 sieve.

No. 3.—This material shall all pass a No. 8 sieve, and not less than 40 nor more than 60 % of it shall pass a No. 100 sieve.

No. 4.—This material shall all pass a No. 100 sieve.

NOTE.—All sieves referred to shall conform to the requirements of United States Standard Sieve Series.

Chemical Properties.—The chemical composition, within the limits prescribed by Section 2 (see definition), shall be a matter of contract.

The following are the A.S.T.M. Standard Specifications (Serial Designation: C 35-25) for gypsum plastering sand:

Composition.—Sand used for plastering in which gypsum is employed shall consist of fine, granular material, naturally or artificially produced by the distintegration of rock containing not less than 80 % by weight of silica, feldspar, dolomite, magnesite, or calcite and shall be free from saline, alkaline organic, or other deleterious substances.

Grading.—It shall be graded from fine to coarse, and when dry not more than 6 % by weight shall be retained on a No. 8 sieve; not less than 80 % by weight shall be retained on a No. 50 sieve; and not more than 6 % by weight shall pass a No. 100 sieve. These sieves shall conform to the requirements of the United States Standard Sieve Series.

The following extract from the A.S.T.M. Standard Specifications for gypsum plasters (C 28-21) gives information in regard to their composition and qualities:

Gypsum Ready-sanded Plaster.—Gypsum ready-sanded plaster is a plastering material in which the predominating cementitious material is calcined gypsum, and which is mixed at the mill with all the constituent parts, including sand, in their proper proportion. It requires only the addition of water to make it ready for use.

Composition.—The following shall govern the composition of gypsum ready-sanded plaster for the desired coats:

(*a*) *Scratch or First Coat.*—Gypsum ready-sanded plaster used for scratch or first coat shall contain not more than two-thirds by weight of sand. The remainder shall contain not less than 75 % of its weight of calcined gypsum. The other 25 % of this remainder may consist of materials to control the working quality, setting time, and fibering.

(*b*) *Browning or Second Coat.*—Gypsum ready-sanded plaster used for browning or second coat shall contain not more than 75 % by weight of sand. The remainder shall contain not less than 75 % by weight of calcined gypsum. The other 25 % of this remainder may consist of materials to control the working quality, setting time, and fibering.

Time of Setting.—The time of set of gypsum ready-sanded plaster shall be as follows:

(*a*) *Scratch or First Coat.*—This plaster shall set in not less than 1½ nor more than 7 hours.

(*b*) *Browning or Second Coat.*—This plaster shall set in not less than 2 nor more than 6 hours.

Tensile Strength.—The tensile strength of gypsum ready-sanded plaster shall be as follows:

(*a*) *Scratch or First Coat.*—This plaster shall have a tensile strength of not less than 75 lb. per sq. in. (5¼ kg. per sq. cm.).

(*b*) *Browning or Second Coat.*—This plaster shall have a tensile strength of not less than 50 lb. per sq. in. (3½ kg. per sq. cm.).

Gypsum Neat Plaster.—Gypsum neat plaster is a plastering material in which not less than 85 % of the cementitious material is calcined gypsum mixed at the mill with other materials.

Composition.—Gypsum neat plaster shall contain not less than 85 % by weight of calcined gypsum. The remainder may consist of materials to control the working quality, setting time, and fibering.

Time of Setting.—Gypsum neat plaster shall set in not less than 1½ hours.

Tensile Strength.—Gypsum neat plaster shall have a tensile strength of not less than 150 lb. per sq. in. (10½ kg. per sq. cm.).

Gypsum Wood-fibered Plaster.—Gypsum wood-fibered plaster is a gypsum plaster in which wood fiber is used as an aggregate.

Composition.—Gypsum wood-fibered plaster shall contain not less than 80 % by weight of calcined gypsum and not less than 1 % by weight of wood fiber made from a non-staining wood. The remainder may consist of materials to control the working quality and setting time.

Time of Setting.—Gypsum wood-fibered plaster shall set in not less than 1½ nor more than 8 hours.

Tensile Strength.—Gypsum wood-fibered plaster shall have a tensile strength of not less than 125 lb. per sq. in. (8¾ kg. per sq. cm.).

Calcined Gypsum for Finishing Coat.—Calcined gypsum for finishing coat may, or may not, contain retarder. It may be classified in two grades: *viz.*, "white" and "gray."

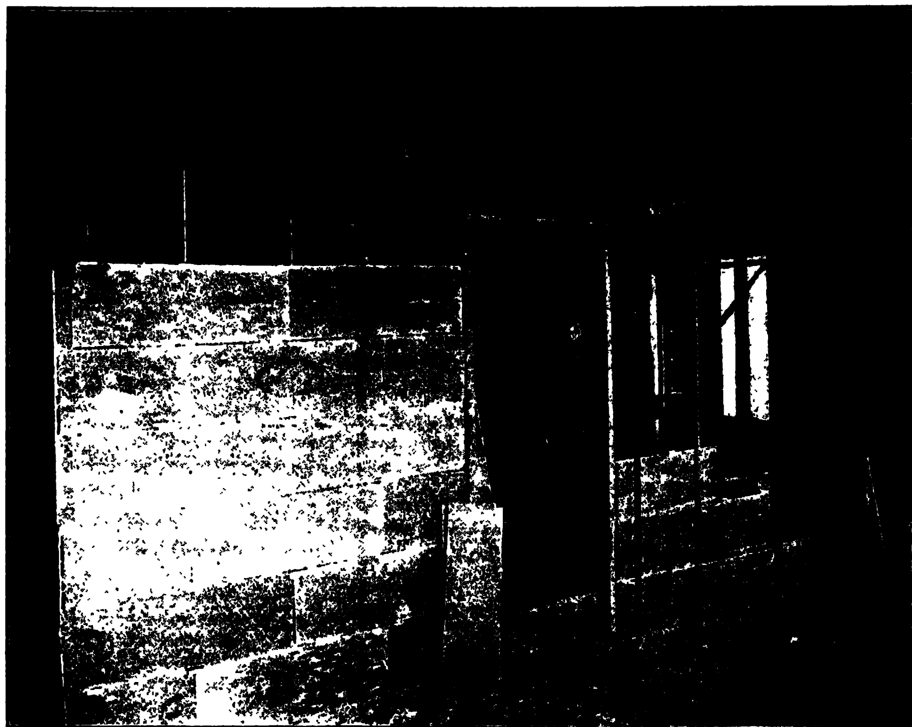


Fig. 31.—Construction of gypsum plaster board partition.

Fineness.—Calcined gypsum for finishing coat shall all pass a No. 14 sieve, and not less than 60 % of it shall pass through a No. 100 sieve.

Note.—All sieve numbers refer to United States Standard Sieve Series.

Time of Setting.—Calcined gypsum for finishing coat when not retarded shall set in not less than 20 min. nor more than 40 min., and when retarded shall set in not less than 40 min. nor more than 6 hours.

Tensile Strength.—Calcined gypsum for finishing coat shall have a tensile strength of not less than 200 lb. per sq. in. (14 kg. per sq. cm.).

90. Gypsum Products.—*Gypsum plaster board, gypsum wall board, gypsum partition tile or block, gypsum roof tile,* and other formed building products are made from calcined gypsum mixed with various aggregates, such as fiber, wood-pulp, etc. They are molded as units by various processes and supplied ready to place on the job.

90*a*. Gypsum Plaster Board.—Gypsum plaster boards are used as a sheet lath or base for gypsum plaster on walls, ceilings, and partitions on the interior of buildings. The following paragraphs are extracts from the A.S.T.M. Standard Specifications for Gypsum Plaster Board (C 37-25):

Gypsum Plaster Board.—Gypsum plaster boards are sheets or slabs having an incombustible core of gypsum and designed to be used as a lath or backing for gypsum plaster on the walls, ceilings, and partitions in the interior of buildings.

Composition.—Gypsum plaster boards consist either of sheets or slabs of gypsum with not more than 15 %, by weight, of fiber intimately mixed; or an incombustible core of gypsum, with or without fiber, surfaced with paper or other fibrous material firmly bonded to the core; or with intermediate layers of such material within the core.

Thickness.—Gypsum plaster boards shall be ¼ (6.3 mm.), ⁵⁄₁₆ (8.0 mm.), ⅜ (9.5 mm.), or ½ in. (12.7 mm.) thick, except that average thicknesses varying not more than ¹⁄₁₆ in. (1.6 mm.) from the nominal thicknesses and local variations of ¹⁄₁₆ in. (1.6 mm.) in the thickness of the individual boards are permissible.

Dimensions.—The nominal width of gypsum plaster boards shall be 32 in. (810 mm.), and the nominal length 24 (610 mm.), 36 (910 mm.) or 48 in. (1220 mm.). A variation of ¼ in. (6.3 mm.) under the specified width and of ⅜ in. (9.5 mm.) under or over the specified length is permissible.

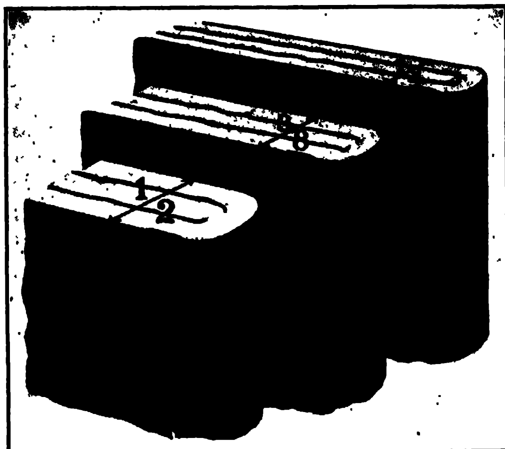


Fig. 32.—Showing construction of Sackett plaster board. Note folded edge and alternate layers of felt and gypsum.

Weight.—The weight of gypsum plaster board per 1000 sq. ft. shall conform to the following:

Thickness		Weight, minimum		Weight, maximum	
Inch	Millimeter	Pounds	Kilograms	Pounds	Kilograms
¼	6.3	1200	544	1500	680
⁵⁄₁₆	8	1250	567	1650	750
⅜	9.5	1400	635	2000	907
½	12.7	2000	907	3000	1361

Strength.—(*a*) Strength-test specimens shall be 12 in. (300 mm.) wide and approximately 18 in. (460 mm.) long. When tested in accordance with the methods described specimens taken from the gypsum plaster boards shall carry not less than the following loads:

Board thickness, inches	Load, pounds	
	Knife edges across fiber of surfacing	Knife edges parallel to fiber of surfacing
⅜	40	20
⁵⁄₁₆	35	17
¼	30	14

(b) With loads equal to or less than those specified in paragraph (a) there shall be no breaking of the bond between the surfacing and the core.

(c) Gypsum plaster boards that are ½ in. (12.7 mm.) thick, or those that are not reinforced on the surfaces with a covering made from fibrous material, when tested as described in paragraph (a), shall carry an ultimate center load of not less than 20 lb. (9.07 kg.).

Finish.—The surfaces shall be such that they will readily receive and retain gypsum plaster. The edges and ends shall be reasonably straight and solid. The corners shall be square with a permissible variation of ¼ in. (6 mm.) in the full width of the plaster boards. Gypsum plaster boards shall be free from cracks and imperfections that will render them unfit for use.

NOTE.—Gypsum plaster boards that have their corners blurred or broken shall be considered acceptable, provided that the broken portion is not more than 1½ in. (38 mm.) in length.

90b. Gypsum Wall Board.—Gypsum wall boards are used without plaster coatings, as a finish on walls, ceilings, and partitions on the interior of buildings. The following is from the A.S.T.M. Standard Specifications for gypsum plaster board (C 36-25).

Gypsum Wall Board.—Gypsum wall boards are sheets or slabs having an incombustible core of gypsum and which, without the addition of plaster, furnish to interior walls, ceilings, or partitions a surface which may receive decoration.

Composition.—Gypsum wall boards consist of an incombustible core of gypsum, with or without fiber, surfaced with paper or other fibrous material firmly bonded to the core.

Thickness.—Gypsum wall boards shall be nominally ⅜ in. (9.5 mm.) in thickness with permissible variations in the average thickness of ± 1/64 in. (0.4 mm.) and with permissible local variations of + 1/32 in. (0.8 mm.) from the normal thickness.

NOTE.—Gypsum wall boards are manufactured in thicknesses from ¼ in. (6.3 mm.) to ½ in. (12.7 mm.) with permissible local variations of + 1/32 in. (0.8 mm.) from the nominal thickness.

Dimensions.—(a) Gypsum wall boards that are to be laid with the joints butted shall have widths of 32 (810 mm.), 36 (910 mm.), or 48 in. (1220 mm.), except that a variation of 3/32 in. (2 mm.) under the specified widths is permissible.

(b) Gypsum wall boards that are to be laid with the joints filled shall have widths ¼ in. (6.3 mm.) less than those specified in paragraph (a), except that the same variation is permissible.

(c) The lengths shall be from 4 (1.22 m.) to 12 ft. (3.66 m.), inclusive, except that a tolerance of ⅜ in. (9.5 mm.) from the length of individual boards is permissible. Special boards may be cut to any desired length within the limits prescribed.

Weight.—The weight of gypsum wall board shall be not less than 1400 lb. (635 kg.) nor more than 2100 lb (952.5 kg.) per 1000 sq. ft.

Strength.—(a) Strength test specimens shall be 12 in. (300 mm.) in width and approximately 18 in. (460 mm.) in length. When tested in accordance with the methods described in Section 13, specimens taken from the gypsum wall boards shall carry a load of not less than 60 lb. (27.22 kg.) when the load is applied across the fiber of the surfacing, and not less than 32 lb. (14.50 kg.) when the load is applied parallel to the fiber of the surfacing.

(b) With loads equal to or less than those specified in paragraph (a) there shall be no breaking of the bond between the surfacing and the core.

Finish.—That surface of the gypsum wall board designed to be exposed on erection shall be true and free from imperfections that would render the wall boards unfit for use with or without decorations. The edges and ends shall be straight and solid. Boards that are to be butted shall have corners square and opposite edges parallel to each other. With boards that are to have the joints filled, a negative variation of ⅛ in. (3 mm.) from parallelism of opposite edges is permissible.

90c. Gypsum Partition Tile or Block.[1]—Gypsum tile for non-bearing fire walls, partitions, and enclosures, and for furring the inside or outside of other walls, consists of hollow or solid tile or blocks which are manufactured at the mills and are delivered for erection on the building site.

Generally, gypsum tile consists of about 95 % finely ground calcined gypsum uniformly mixed with from 2 to 5 % by weight of fibrous material, this compound being mixed to a plastic state with water, and molded in the form of the desired units.

Commercial standard sizes and weights per square foot for the uses stated are about as follows:

1½-in. split furring (1½ × 12 × 30 in.)	4.9 lb.
2-in. split furring (2 × 12 × 30 in.)	9.4 lb.
1½-in. solid tile or block (1½ × 12 × 30 in.)	7.2 lb.
2-in. solid tile or block (2 × 12 × 30 in.)	9.4 lb.
3-in. hollow tile or block (3 × 12 × 30 in.)	9.4 lb.
4-in. hollow tile or block (4 × 12 × 30 in.)	13.0 lb.
5-in. hollow tile or block (5 × 12 × 30 in.)	15.6 lb.
5-in. solid tile or block (5 × 12 × 30 in.)	20.0 lb.
6-in. hollow tile or block (6 × 12 × 30 in.)	16.6 lb.
8-in. hollow tile or block (8 × 12 × 30 in.)	22.4 lb.

[1] This material supplied by V. G. Marani, Chief Engineer of the Gypsum Industries Association.

Special sizes of gypsum tile can be made to order in any size, thickness, or shape to meet requirements.

For ventilation ducts or special construction the tile can be manufactured with one or both faces smooth and of any desired density and strength.

Gypsum plaster tile are used as a substitute for clay tile, cement blocks, brick, concrete, metal lath and plaster, sheet metal, and wood lath and plaster in the following nonbearing constructions:

Corridor walls, partitions, and wall furring.
Fire division walls.
Elevator, stairway, and dumb waiter enclosures.
Light wells, pipe chases, and vent ducts.
Floor fillers, also roof fillers for insulating purposes.
False columns, pilasters, etc.

In buildings of fireproof construction or for any construction required to be of high fire-resisting value, gypsum til [illegible]d for the following, in addition to the uses (as stated) for the protection of combustible construction:

Non-bearing, "fire" or "fire division" walls.
Steel girder, truss beam, and lintel protection.

All partitions, walls, furring, etc., should be started upon solid flooring. In all fireproof buildings they should be started upon fireproof floor or other fireproof construction; and in all buildings "fire" or "fire division" walls should be constructed upon fireproof floors or fireproofed steel supporting beams or girders. All corners should be bonded, and connections to other walls should be suitably bonded or anchored.

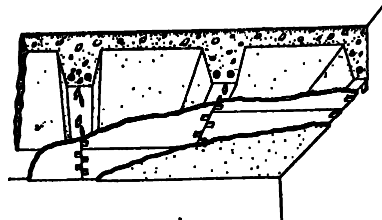


Fig. 33.—Showing application of Sackett soffit ceiling on reinforced concrete construction. Note how flanges of steel clips imbedded in concrete joists are bent each way holding Sackett board in place.

Generally, gypsum furring should be laid up against the wall or partition to be furred and be securely wired or spiked to such. Free standing furring (not against a wall or partition) should be secured by metal separators spaced not further apart than 3 ft. in any direction.

Trim, grounds, chair rail and similar fixtures should be nailed directly to the tile or block. Black boards, heavy toilet fixtures, mantels, etc., should be secured to 2-in. nailing blocks which are nailed to and are full size of the end of the gypsum tile.

All tile construction, furring, girder, truss, beam, and lintel protection of gypsum should be laid up in a mortar composed of not less than one part of gypsum plaster to not more than two parts of clean sharp sand by weight. Steel construction may be protected by pouring the gypsum around the member in form work and to the required thickness. All door buck and similar framing should be anchored to the gypsum construction in a suitable manner.

The following extracts from the A.S.T.M. Standard Specifications (C 52-25) for gypsum partition tile or block give an idea of the uses, composition, dimensions, and other qualities of this product:

Gypsum Partition Tile or Block.—Gypsum partition tile or block is a building unit used for non-bearing construction in the interior of buildings.

Note.—The words "tile" and "block" are synonymous and are used so as to be in accord with certain freight-association nomenclature.

Uses.—(*a*) It is also used as a protection for columns, elevator shafts, etc., against fire.

(*b*) Gypsum cored tile, 3 or 4 in. in thickness, may be split and used for furring purposes.

Composition.—Gypsum tile consists of gypsum with or without an aggregate.

Form and Size.—Gypsum partition tile shall be rectangular in shape with straight and square edges and true surfaces. They may also be of special shape provided the requirements, as otherwise mentioned herein, are met. They may be solid or cored and shall preferably be 12 × 30 in. in face dimensions.

Core Spaces.—(*a*) The core spaces shall be symmetrically spaced.

(*b*) *Shell Thickness.*—The minimum cross-sectional shell dimensions of gypsum partition tile with circular, elliptical, or rectangular core spaces shall conform to the following:

Thickness of tile or block, inches	Side or edge circular core	Shell thickness, inches elliptical or rectangular core
$2\frac{1}{2}$	$\frac{1}{2}$	$\frac{9}{16}$
3	$\frac{1}{2}$	$\frac{11}{16}$
4	$\frac{3}{4}$	$\frac{13}{16}$
5	$\frac{7}{8}$	$1\frac{1}{8}$
6	$\frac{1}{2}$	$\frac{15}{16}$
8	$\frac{3}{4}$	$\frac{13}{16}$

In tile or block having circular cores, the sum of the widths of the two side shells plus the width of the center vertical web shall be not less than 2 in. in the case of 6-in. tile and not less than 2½ in. in the case of 8-in. tile.

In tile or block having elliptical or rectangular cores, the sum of the widths of the two side shells plus the width of the center vertical web shall be not less than 2¾ in. in the case of 6-in. tile and not less than 3¼ in. in the case of 8-in. tile.

Dimensions.—(*a*) Gypsum tile may be of any convenient length and height, but, in general, they shall not exceed 30 in. in length and 12 in. in height. The thickness shall be uniform throughout and within the limits specified in paragraph (*b*).

(*b*) *Thickness.*—Gypsum tile or block shall conform to the specified thicknesses with the following permissible variations:

Nominal size of tile or block, inches	Minimum thickness, inches	Maximum thickness, inches
1½ (furring)	1⅜	1⅝
2 (furring)	1⅞	2⅛
2	2	2¼
2½	2⅜	2¾
3	2⅞	3¼
4	3⅞	4¼
5	4⅞	5¼
6	5¾	6¼
8	7¾	8¼

(*c*) *Dimension Determinations.*—Overall dimensions shall be measured from opposite face to opposite face of the tile or block, the greatest measurement observed being taken as the dimension.

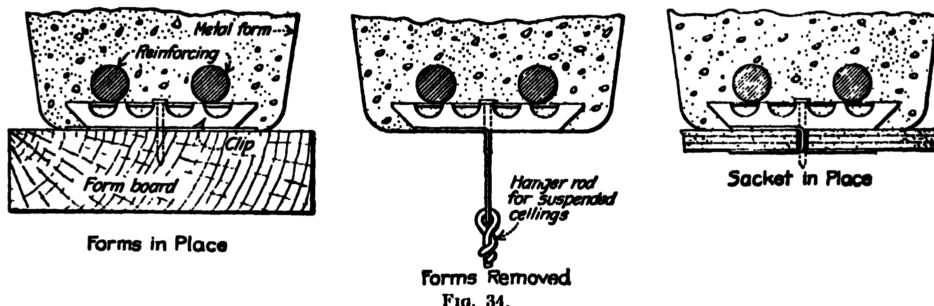


Fig. 34.

Sectional dimensions of cored tile shall be taken 1 in. in from the ends of the tile or block, the least measurement observed being taken as the dimension.

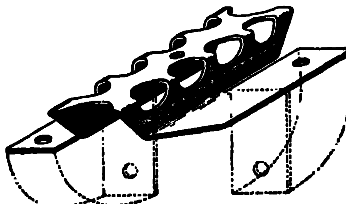
Shell dimensions shall be measured from the surface of the core space to the normal surface of the tile or block inside the scoring.

(*d*) *Dimension Tolerances.*—A variation of ¼ in. in the nominal width and ⅜ in. in the nominal length of the tile or block is permissible.

(*e*) *Scoring.*—The scoring upon gypsum tile or block shall be of such a nature as not to reduce materially the shell thickness.

Strength.—(*a*) When tested in accordance with the methods described the compressive strength of gypsum tile or block shall be not less than 75 lb. per sq. in. for the average of five specimens tested.

(*b*) When completely saturated, the compressive strength shall be not less than 33⅓ % of the strength required for such tile or block when dried to constant weight.


Fig. 35.—Metal clip.

Absorption.—The rate of absorption of gypsum tile or block shall be not less than 8 cc. nor more than 30 cc. for the first minute, nor less than 4 cc. for each of the next 5 subsequent minutes.

Fire Resistance.—In locations where fire resistance is an essential property, gypsum tile or block shall meet the requirements of the Standard Specifications for Fire Tests of Materials and Construction (Serial Designation: C 19) of the American Society for Testing Materials, as they apply for the construction in which the tile are used.

CEMENT

BY GEORGE A. HOOL

Cementing materials used in structural work may be divided into two main classes—non-hydraulic and hydraulic. Non-hydraulic cements, as the name implies, will not set and harden under water; while hydraulic cements will harden in either water or air. Following is a list of the structural cements of commercial importance:

Non-hydraulic	Gypsum plasters Common lime
Hydraulic	Hydraulic lime (*Grappier cement*, a by-product) Puzzolan cement Natural cement Portland cement (Adulterated or modified Portland cement) Quick-hardening (alumina) cement.

Gypsum plasters and common lime are treated in preceding chapters. This chapter treats of hydraulic cements only.

91. Hydraulic Lime.—Hydraulic lime is made by burning argillaceous or silicious limestone at a temperature not less than 1000 deg. C. When showered with water the product slakes completely or partially without sensibly increasing in volume, and possesses hydraulic properties due to the combination of calcium with silica contained in the limestone as an impurity, forming calcium silicate. It is the universal practice to slake the lime at the place of manufacture on account of the better results obtained.

Grappier cement is a by-product in the manufacture of hydraulic lime, produced by grinding the lumps of underburned and overburned material which do not slake. As might be inferred, grappier cement possesses properties similar to those of hydraulic lime.

Hydraulic lime is not manufactured in the United States on account of the abundance of raw materials suitable for the manufacture of Portland cement, with which hydraulic lime cannot compete as a structural material. A number of hydraulic limes and grappier cements are marketed as "non-staining cements"—that is, they do not stain masonry. For this reason a considerable amount of this cementing material is annually imported from Europe for purposes of architectural decoration.

92. Puzzolan or Slag Cement.—Puzzolan cement is made by incorporating hydrated lime with a silicious material, such as granulated blast-furnace slag, of suitable fineness and chemical composition. In Europe a natural puzzolanic material, such as volcanic ash, is used at some plants in place of the blast-furnace slag.

Although this type of cement possesses hydraulic properties, it should not be confused with *slag Portland cement* (sometimes called *steel Portland cement*) which is produced by calcining finely divided slag and lime in a kiln and pulverizing the resulting clinker.

Puzzolan cement is not strong or reliable as either natural or Portland cement and should be used only in unimportant structures or in unexposed work, such as foundations, where weight and bulk are more important than strength.

93. Natural Cement.—Natural cement, as its name implies, is made from rock as it occurs in nature. This rock is an argillaceous (clayey) limestone, or other suitable natural rock, and it is burned at a temperature of from 900 to 1300 deg. C., the clinker being then finely pulverized. The product does not slake, but possesses strong hydraulic properties, calcium silicate being formed and acquiring strength and rigidity through crystallization.

Natural cement is adapted to many uses, but its relatively low strength and slow hardening limit its field to structures where high stresses will not be imposed for several months after placing the concrete, as in large or massive structures where weight and mass are more essential than early strength—that is, in such structures as dams, abutments, foundations, and many underground structures. Mortar made with natural cement (either alone or mixed with lime mortar) is excellent for laying ordinary brick and stone masonry.

94. Portland Cement.—Portland cement is made by finely pulverizing the clinker produced by burning a definite artificial mixture of silicious (containing silica), argillaceous (containing

alumina), and calcareous (containing lime) materials to a point somewhat beyond where they begin to fuse or melt. The product is one that does not slake and possesses strong hydraulic properties. The essential components of Portland cement—namely: silica, alumina, and lime—are obtained from many different sources, but the proportions used of the raw materials are always such that the chemical composition of the different Portland cements is constant within narrow limits. The percentages of the principal components range about as follows:

SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %
19 to 25	5 to 9	2 to 4	60 to 64	1.0 to 2.5

(Small amounts of alkalies (K_2O and Na_2O) and sulphur trioxide (SO_3) are also present. Magnesia (MgO) is considered by some as an impurity, while other investigators claim it is equivalent to lime (CaO) in its action. Alumina (Al_2O_3) and iron oxide (Fe_2O_3) do not act entirely alike but are usually considered to have the same functions.) The specific gravity of Portland cements range from 3.1 to 3.20, with an average of 3.15.

Portland cement is by far the most important cementing material used in modern engineering construction. It is adapted for use in concrete and mortar for all types of structures where strength is of special importance, or in structures exposed to wear or to the elements. It should invariably be employed in reinforced-concrete construction because of its high early strength and generally uniform quality.

A number of special cements employing Portland cement as a base are made by grinding in adulterating materials after calcination. These adulterants include clay, slaked lime, sand, slag, natural cement, limestones, and natural puzzolanic material or tufa. The action of these materials is essentially to promote combination between lime from the cement and silica from the adulterant, with formation of silicate of lime. In some cases these silicious adulterants improve the quality of concrete made from such cements, but this result cannot be expected from all forms of adulteration.

Sand and puzzolanic materials have, perhaps, been used the most extensively and successfully of any of the adulterants, producing products known as *sand cement* and *tufa cement* respectively. These cements have been used principally on large work where freight rates are high and long wagon hauls combine to make the cost of undiluted Portland cement excessive. Cement specifications in common use are of a character to exclude any grinding in of materials after calcination, presumably on the ground that specifications permitting any adulteration would be subject to abuse so that the results obtained would be uncertain.

95. Setting and Hardening of Portland Cement.[1]—The setting and hardening of Portland cement is caused principally by hydration in the order named of the three major constituents—$3CaO \cdot Al_2O_3$, $3CaO \cdot SiO_2$, and $2CaO \cdot SiO_2$. When water is added to Portland cement, these constituents form first amorphous and later both crystalline and amorphous hydrated materials which act much as does ordinary glue, except that since they are of mineral origin and largely insoluble, hardening progresses even under water.

Of these hydration products, the compound tri-calcium aluminate ($3CaO \cdot Al_2O_3$) when mixed with water sets and hardens very quickly; tri-calcium silicate ($3CaO \cdot SiO_2$) sets and hardens somewhat less rapidly; and di-calcium silicate ($2CaO \cdot SiO_2$) reacts slowly. Hardening occurs only after the lapse of a long period of time. The *initial set* of cement is due undoubtedly to the hydration of $3CaO \cdot Al_2O_3$; the early hardness and cohesive strength is due to this hydration and to that of the $3CaO \cdot SiO_2$; while the gradual increase in strength is due to the further hydration of these two compounds together with the hydration of the $2CaO \cdot SiO_2$.

The compound $3CaO \cdot SiO_2$ appears to be the best cement constituent of this group, as it is the only one of the three which when mixed with water will set and harden within a reasonable time to form a mass which is comparable in hardness and strength to Portland cement. Although $3CaO \cdot Al_2O_3$ acts and hardens rapidly, it is rather soluble in water and is not particularly durable or strong. The compound $2CaO \cdot SiO_2$, however, requires too long a time to harden to be in itself a valuable cement material.

96. Testing of Portland Cement.—For standard methods of cement testing, see A.S.T.M. standards adopted in 1926.

96a. Sampling.—Tests should be conducted only on representative samples. For methods of sampling, see A.S.T.M. standards adopted

[1] See KLEIN and PHILLIPS: *Tech. Paper*, 43, U. S. Bureau of Standards.
BATES AND KLEIN: *Tech Paper*, 78, U. S. Bureau of Standards.

96*b*. Uniformity in Cement Testing.—In order to obtain results in cement testing which will be of the greatest value, definite and uniform methods should be used. Results depend not only on the quality of the cement but also on the temperature and percentage of water used in mixing, the method of mixing and molding test specimens, the temperature and humidity of the air, the character of the sand used, and the type of apparatus employed.

96*c*. The Personal Factor.—The personal factor has considerable effect on results obtained in cement testing and, on this account, only experienced, well-qualified men should be employed in making tests. Results by untrained or careless operators are really worse than nothing and may be positively misleading. The comparative results, however, by any one experienced observer are generally consistent and are of value. It is usually advisable to have the testing done at some well-established and properly equipped cement-testing laboratory.

96*d*. Kinds of Tests.—The following cement tests made regularly are recommended for construction work of importance and also in all cases where the cement to be used does not work satisfactorily:

Fineness.
Time of setting.
Tensile strength of standard mortar. (Compressive strength of standard mortar the best criterion.)
Soundness.

On unimportant construction it is generally safe to use a well-known brand of Portland cement without testing, or to make simply the test for soundness.

96*e*. Fineness.—Fine grinding has a great influence on the properties of cement. It increases the ability of the cement to react readily with water and enables the cement particles to coat the sand grains more thoroughly. In other words, the finer the cement, all other conditions being the same, the stronger will be the mortar produced with a given sand. Not less than 78% passing a 200-mesh sieve should be adequate for most commercial work.

The fineness of cement is measured by determining the percentage by weight which will be retained on a standard 200-mesh sieve. Standard specifications[1] require that the residue shall not exceed 22 %. Most mills are now equipped to grind cement to such a fineness that even less than 10 % is retained.

96*f*. Normal Consistency.—Tests for setting, strength, and soundness are greatly influenced by the quantity of water used in mixing. In order to have all results comparable with one another, a determination is made in each case of the quantity of water necessary to be added to a given weight of cement to give a standard or normal consistency (see *Proc.* A.S.T.M., 1917).

96*g*. Time of Setting.—The time of setting of a cement may vary within wide limits and is no certain criterion of quality, but it is important in that it indicates whether or not the cement can be used advantageously in ordinary construction. A cement may set so quickly that it is worthless for use as a building material (since handling cement after it commences to set weakens it and causes it to disintegrate), or it may set so slowly that it will greatly delay the progress of the work.

Age of cement has a great effect upon the setting time, and tests should preferably be made after delivery of the cement on the work. Most cements absorb moisture from the air and lose some of their hydraulic property on storage.

Aside from the consideration of age, the conditions which accelerate setting are: finely ground and lightly burned material; dry atmosphere; small amount of water used in gaging; and high temperature of both water and air. Since the time of set is influenced by so many factors, tests should always be made with extreme care under standardized conditions.

There are two distinct stages in setting: (1) the initial set; and (2) the hard or final set. The best cements should be slow in taking the initial set but after that should harden rapidly. Portland cement should acquire the initial set in not less than 45 min. when the Vicat needle is used or 60 min. when the Gillmore needle is used, and hard set in not more than 10 hours.[1] The time of initial set is controlled largely by the amount of sulphate (gypsum or *plaster of Paris*) which is added in making the cement.

A cement has taken its initial set when it will not thoroughly reunite along the surfaces of a break. It has taken its final set when it begins to have appreciable strength and hardness.

[1] See standard specifications in Appendix *B*.

96h. Tensile Strength.—The object of testing cement in tension is to obtain some measure of the strength of the material in actual construction. In other words, tests of tensile strength are made primarily to determine whether the cement will be likely to have a continued and uniform hardening in the work, and whether it will have such strength when placed in mortar or concrete that it can be depended upon to withstand the strain placed upon it.

The small shapes made for testing are called *briquettes* and have a minimum cross-sectional area of 1 sq. in.—that is, at the place where they will break when tested. Standard mortar used in testing is composed of 1 part cement to 3 parts of standard sand from Ottawa, Ill.

It is customary to store the briquettes, immediately after making, in a damp atmosphere for 24 hours. They are then immersed in water until they are tested. This is done to secure uniformity of setting, and to prevent the drying out too quickly of the cement, thereby preventing shrinkage cracks which greatly reduce the strength.

Specifications for tensile strength of cement usually stipulate that the material must pass a minimum strength requirement at 7 and 28 days. This is required in order to determine the gain in strength between different dates of testing so that some idea may be obtained of the ultimate strength which the cement will attain. A first-class cement, when tested, should give the values for tensile strength stated in the standard specifications. (For standard methods of tests, see A.S.T.M., 1926.)

96i. Relation between Tensile and Compressive Strength.—Since cements are rarely depended upon to withstand tensile stresses, the test for tensile strength has undoubtedly become standard on account of the popular belief that there exists a more or less definite and constant relation between the tensile and compressive strengths. It can be shown, however, that the ratio of compressive to tensile strength of cement mixtures is by no means constant at all ages and varies greatly with different cements and with different mixtures. Thus the tensile strength cannot usually be regarded as any more than a very approximate indication of the probable compressive strength of the same cement.

96j. Compressive Strength.—Compressive strength of cement mortar is undoubtedly a better criterion by which to judge the suitability of a cement for use in construction. The American Society for Testing Materials has tentative specifications and methods of tests for compressive strength of Portland cement mortar[1] which, when adopted as standard by the Society, will be inserted in and made a part of the American Specifications and Methods of Tests for Portland Cement.

96k. Soundness.—A cement to be of value must be perfectly sound; that is, it must remain constant in volume and not swell, disintegrate, or crumble. Excess of either lime, magnesia, or sulphates may cause unsoundness. The usual method of testing is to form a small pat of neat cement about 3 in. in diameter, ½ in. thick at the center, and tapering to a thin edge. This pat should remain 24 hours in moist air and 5 hours in an atmosphere of steam at a temperature between 98 and 100 deg. C. upon a suitable support 1 in. above boiling water. To pass the soundness test satisfactorily, the pat should remain firm and hard, and show no signs of cracking, distortion, checking or disintegration. The steam test is what is called an *accelerated* test and is for the purpose of developing in a short time (5 hours) those qualities which tend to destroy the strength and durability of a cement.

96l. Specific Gravity.—A test for finding the specific gravity of Portland cement was originally considered to be of value in detecting adulteration and underburning, but is no longer thought to be of much importance in view of the fact that other tests lead to more definite conclusions. One trouble has been that specific gravity is not alone lowered by the above causes. Seasoning of either cement or cement clinker, for instance, although known to be desirable and in some cases absolutely necessary, lowers the specific gravity materially. On the other hand, many underburned cements show a specific gravity much higher than that set by standard specifications. These considerations, together with the fact that the principal adulterants have a specific gravity very near that of Portland cement, make it difficult in the specific gravity test to obtain results from which accurate conclusions can be drawn. The test for specific gravity is not included in the present A.S.T.M. Standards.

96m. Chemical Analysis.—If the tests of a cement for time of setting, strength, and soundness seem to indicate adulteration, resort may be had to chemical analysis. Such

[1] See *Proc.* of the Society, Vol. XX (1920), Part I, p. 599.

analysis is not usually made in routine commercial testing. Chemical analysis not only serves as a valuable means of detecting adulteration but also shows the amounts of magnesia (MgO) and sulphuric anhydride (SO_3) contained in the cement. Specifications usually limit the amount of MgO to about 5% and SO_3 to about 2% because of fear that more of these materials may make the cement unsound.

97. Specifications for Portland Cement.— Standard specifications are given in Appendix *B*.

98. Containers for Cement.—Cement may be obtained in cloth or paper bags, in bulk, and in barrels.

Cloth bags are the containers most generally used since manufacturers will refund the extra charge for the bags when returned in good condition. The consumer, however, must prepay the freight when returning the empty bags to the mill. The cloth bag will stand transportation, and its size and shape make it convenient to handle. If properly cared for, it may be used over and over again. Paper bags are more delicate and have no return value. Wooden barrels are advisable when the work is in a damp location, as in marine construction. Bulk cement requires special preparations for handling and storage.

99. Storing of Cement.—Cement either in containers or in bulk should be stored within a tight, weather-proof building which will protect the cement from dampness, at least 8 in. away from the ground and an equal distance from any wall, so that free circulation of air may be obtained. In case the floor of a storage building is laid directly above the ground, it would be well to give the cement an additional 8-in. elevation by means of a false floor, so as to insure ventilation underneath. The cement should further be stored in such a manner as to permit easy access for proper inspection and identification or removal of each shipment. When cement is not mill tested, a proper period before cement is needed should be allowed by the contractor for inspection and tests, this period being determined by the provisions of the specifications governing his contract.

Where cement in bags is stored in high piles for long periods, there is often a slight tendency in the lower layers to harden, caused by the pressure above; this is known as *warehouse set*. Cement in this condition is in every way fit for service and can be reconditioned by letting each sack drop on a solid surface before using the cement contained.

100. Seasoning of Cement.—A moderate amount of *seasoning* in weather-tight sheds often improves the quality of the cement. Fresh cement contains small amounts of free or loosely combined lime which does not slake freely and causes expansion after the mass has set, endangering the structure in which it is used. During the time of seasoning such free lime is changed first to hydrate and then to carbonate of lime which does not swell on wetting. Usually cement is seasoned at the mills before shipping, but, with the best mills, the stock house may run so low in periods of rush that a chance will be taken on fresh material. Well-seasoned cement, therefore, may be lumpy, but the lumps are easily broken up. If, however, the cement has been subjected to excessive dampness, or has been wet, lumps will be formed which are hard and difficult to crush. A distinction should be made, so that the latter will not be used without sifting and rejection of hardened portions.

101. Quick-hardening (Alumina) Cement.—These cements have a high alumina content and are made from a fused mixture of limestone and bauxite (an aluminum ore). At present, the cost of alumina cement is more than that of Portland cement, and, consequently, the alumina cement is used in new construction and repair work where the saving in time justifies the added cost.

Concrete, made with a quick-hardening cement, secures "initial" set in about the same time as a Portland cement concrete and then hardens and gains strength much more rapidly. The 1-day compressive strength of a quick-hardening cement concrete is approximately equal to the 28-day compressive strength of a Portland cement concrete of similar proportions. The 28-day compressive strength of a quick-hardening cement concrete is approximately 30% more than its 1-day strength. The quick hardening is accompanied by a considerable development of heat, and, consequently, the concrete should be kept well sprinkled to prevent it from drying out too rapidly. This heat development is an advantage in cold-weather construction.

102. Weight of Cement.—A barrel of Portland cement weighs 376 lb., not including the barrel, and a bag of Portland cement weighs 94 lb.; in other words, there are four bags to a barrel.

A barrel of natural cement varies in weight according to the locality in which it is manufactured. A barrel of Western cement usually weighs 265 lb.; and a barrel of Eastern cement, 300 lb. A bag of natural cement is usually one-third of a barrel.

A barrel of puzzolan cement is usually assumed to contain 330 lb. net, and there are four bags to the barrel.

A cement barrel weighs about 20 lb. on an average.

CONCRETE AGGREGATES AND WATER

By Nathan C. Johnson

103. Definitions.—"Aggregates" is a general classifying term applied to those inert (*i.e.*, chemically inactive) materials, both fine and coarse, which, when bound together by cement, form the substance known as concrete. Fine aggregates are materials such as natural sand or rock screenings. Coarse, or large aggregates, or ballast are materials such as natural gravel, crushed rock, or by-product materials such as cinders or crushed blast-furnace slag.

104. General Requirements.—Aggregates, fine and coarse, compose approximately 90% or more of the substance of concrete. From this it follows that the properties of aggregates must correspond and be at least equal to the properties desired in the concrete.

The usual service requirements are that aggregates shall be dense, hard, durable, structurally strong and, for aggregates in concretes exposed to water action, insoluble. Further, since concrete is formed by bonding of aggregates with cement, they must permit by their physical characteristics (such as roughness) the adhesion of cement; and always all particles must be clean, so that a surface coat of one kind or another may not prevent physical contact with cement, or destroy its properties through chemical action.

105. Classification of Aggregates.—The usual classification of aggregates is into two divisions, based upon size.

Coarse aggregates are all particles of gravel, crushed stone, or other materials above ¼ in. diameter.

Fine aggregates are all particles below ¼ in. in size. Particles of such size are further divided by defining "sand" as all mineral particles from 2 to 0.5 mm. in diameter; "silt," all particles from 0.5 to 0.005 mm. in diameter; "clay," all particles having a diameter less than 0.005 mm; and "loam" as a mixture of any of the above finer varieties with organic matter—*i.e.*, of vegetable or animal origin. It is particularly such organic matter rather than size of particle which renders loam unfit for concrete work, as through some chemical action not yet fully understood, possibly through formation of an organic acid, it injures or inhibits the proper action of cement.

106. Qualities of Fine Aggregates—General.—When it is remembered that the finer natural materials are derived from rocks by disintegration and by "weathering," or breaking down through frost action, water and wind erosion, or kindred agencies, the differences in quality so often found in sand deposits, with possibly the presence of foreign materials, are not surprising. Further, sands necessarily partake of the qualities of the rock from which they are derived. Silicious quartz sands are best for concrete work, but crushed sands from any durable rock will answer, if natural sand of proper quality cannot be obtained.

107. Qualities of Coarse Aggregates—General.—For coarse aggregates, any crushed rock of durable character, or any clean, hard, natural gravel not subject to ready disintegration may properly be used. In general, the better the stone or gravel, the better the resulting concrete. For this reason, granite, trap, or hard limestone are preferred for large aggregates, but any rock will serve which is sound, which has adequate strength and does not contain objectionable mineral inclusions liable to decompose, such as iron pyrites, FeS_2, which may form sulphuric acid by oxidation.

Since the properties of any concrete are so closely related to the properties of its components, it is essential to an understanding of the value of any stone as an aggregate that something be known of the origin, nature, and properties of the varieties in common use.

108. Materials Suitable for Coarse Aggregates.—Roughly, rocks suitable for use as aggregate fall into three groups. These are: (1) granite and other igneous rocks; (2) sandstones and other sedimentary rocks; (3) limestones and related rocks. A fourth division comprises slates and shales, but as these weather rapidly with formation of clay, they are unsuited for use in concrete.

The physical character of a rock depends upon two things—its mineral constituents and its structure. If the mineral constituents are themselves durable, but massed together in a manner structurally weak, rapid weathering, with formation of sand through liberation of mineral grains, is to be expected. Such a rock would make a poor concrete. On the other hand, a dense structure with like mineral constituents would make an excellent aggregate. A dense structure and weak mineral constituents are sometimes associated, but Nature has generally cared for such rocks by bringing about their decomposition, so that they exist only as sand.

109. Igneous Rocks.—Igneous rock is a general term descriptive of all rocks formed from molten matter which has consolidated either into mineral, or glass, or both. Among such rocks are granite and trap rock.

109*a*. Granite.—Granite is well known by its characteristic appearance. In structure, it is a blend of quartz (crystallized silica dioxide), orthoclase, and mica, though this latter may be replaced by hornblende. It is exceedingly dense, hard and durable, consisting entirely of minerals with no glass or uncrystallized material between its constituent grains.

Granites possess the strength and durability desirable in an aggregate, but they are of low toughness. In addition, if used in concretes exposed to more than ordinary heat, as in chimneys, there is a decided tendency to disintegrate, due to unequal mineral grain expansions. Granites are not often used as aggregate, their ornamental value precluding less profitable use.

109*b*. Trap Rock or Diabase.—Trap rock and fine-grained basic and volcanic rocks are generally hard, of high abrasive value adhering well to cement. These rocks have a closely interlaced mineral structure and generally good resistance to stress. Care should be taken not to choose a trap rock having a considerable percentage of iron present in low oxide form, as this may absorb oxygen, forming a higher oxide, with expansion and probably rupture.

In general, trap rock (and rock of similar character, in which class are included many of the "green-stones") makes a very excellent aggregate although in some respects its excellence has been exaggerated. It has, however a very high compressive strength and, as this quality is very desirable in concretes, its use has become widespread It is not always procurable without excessive cost but, where price is not prohibitive, its use is advantageous.

110. Sedimentary Rocks.—To the sedimentary series of rocks belong all those solidified deposits which have accumulated at the bottom of bodies of water. Originally, these materials were derived from the land surface and transported to the sea or lakes, either by mechanical carriage, or by solution in water. Many of the minerals contained in sedimentary rocks were derived directly from the decay of igneous or volcanic rocks, although additional chemical changes supplementing this more or less complete decomposition of the original minerals may have resulted in the formation of new minerals found in the sedimentary series. With passage of time and the action of various chemical and mechanical agencies, these sedimentary deposits solidified into the stratified rocks of one kind or another found throughout the entire surface of the earth.

110*a*. Sandstone.—One of the most important of the sedimentary rocks is sandstone. In structure, it is natural concrete, composed of finely divided mineral particles, cemented together in more or less close relation by iron or alumina or by calcium compounds. The character of any sandstone depends, therefore, on the mineral character of its component grains; on the size and shape of these grains; on their arrangement within the rock; and on the nature of the material cementing them together.

Quartz particles form by far the greatest percentage and the most desirable constituent of sandstone. Feldspar is also frequently present, and occasionally, hornblende, chlorite, garnet, magnetite, and calcite. In the best sandstones, the grains are arranged uniformly through the mass, although frequently coarser and finer particles are arranged in layers, giving a stratified appearance to the stone.

So far as its use in concrete is concerned, the most important feature of a sandstone is the nature of the cementing material combining its constituent grains. *Argillaceous sandstones* in which the cementing material is lime (usually lime carbonate) may be crushed with comparative ease, but they disintegrate rapidly on exposure to weathering agents, such as water or air. Such stone may be readily identified by its effervescence when treated with a drop of hydrochloric acid. *Sandstones cemented by oxide of iron* are generally red in color, the shade being a rough indication of the amount of iron present. Many of these sandstones disintegrate very rapidly on exposure to the weather, forming the so-called "rotten stones" so often found in gravel.

Sandstones cemented solely by clay should never be used in concrete, as the simple penetration of moisture is sufficient to disintegrate them, rendering them practically valueless as aggregate. A good accelerated test is to boil ¼-in. fragments of the stone in water. Rapid disintegration indicates a weak stone, with a tendency to weather rapidly, and unsuited for use as aggregate.

110b. Limestone.—Limestone is carbonate of lime deposited on the floors of bodies of water and subsequently hardened into rock. This precipitation of lime may have been effected from the water, or through the agency of animal or vegetable life. This is to say, some limestones are chemical precipitates, while others are formed from the shells and other hard parts of animals, as well as from hardened tissues of certain plants. Such plant and animal forms fossilized are often seen in limestone fragments.

Compact limestone varies in texture from coarse to exceedingly fine. It is only occasionally pure carbonate of lime, usually containing greater or less percentages of magnesia. Either magnesia, limestone, or pure calcic limestone is very well suited for use as a concrete aggregate. Any considerable percentage of clay in limestone, however, is very undesirable, as it softens the rock and renders it very liable to disintegration. Limestone is found in many colors. White, gray, yellow, blue, and green are those of most frequent occurrence.

In general, limestone makes a very good coarse aggregate for concrete. When crushed to the finer sizes, it has a flaky fracture which renders it somewhat unsuitable for use as sand unless it is rerolled. Natural limestone sands are of infrequent occurrence, as limestone is soluble to as high a percentage as 90 %, so that the usual weathering processes result in solution, rather than fragmentary disintegration.

111. Metamorphic Rocks.—Rocks of either igneous or sedimentary origin have often been subjected to such severe treatment in the long course of geologic history, that their ordinary character is much altered. Crushing of the earth's crust, the weight of overlying material, and contact with hot molten rock from the interior are among the causes contributing to the change. Such rocks are classed as "metamorphic."

There are many metamorphic rocks, the whole group constituting a very high percentage of the surface of the earth's crust. Some of them are of value as aggregates in concrete; while others, notably the slates and shales, have a weak stratified structure and weather so rapidly that their value in concrete is almost nothing.

112. Gravel.—Gravel of good quality makes excellent concrete (see *Tech. Paper* 58, Bureau of Standards, Washington, D. C.). Gravel is nothing more nor less than natural rock, broken away from parent ledges and worn round by the rolling of streams. Its natural properties, therefore, are identical with the rock of which it once formed a part. Provided it has not decayed through being in relatively small masses, the properties natural to this parent rock are to be expected of a gravel. The surface of gravel is usually very rough; and from considerations of character of surface presented for adhesion of cement, it should produce as good as, and even better, concrete than crushed stone. Certainly, there is no reason against its use, provided it is clean and of good mineral quality.

113. Blast-furnace Slag.—Slag from blast furnaces, crushed to proper size, has much to recommend it for mass construction. Slag is a fairly hard though very porous material, of fairly high compressive strength; and in certain localities is relatively cheap as compared to stone of good qualities. Offering a rough, pitted surface for the adhesion of cement, it produces a very strong concrete when of proper quality.

114. Cinders.—Furnace cinders as an aggregate are used only in inferior grades of mass concrete, or for fireproofing. Cinders have low structural strength, high porosity, and oftentimes as an added objection, high sulphur content. In more than one instance, sulphuric acid resulting from sulphur decomposition in cinder concrete floors has eaten away conduits and piping, and has even attacked reinforcing and structural steel. Cinder concrete is of value chiefly because of its cheapness and low specific gravity, but discrimination is required in its use.

115. Materials Suitable for Fine Aggregates.—All fine aggregates are essentially rock fragments, crushed to varying degrees of fineness, either by the natural processes of weathering, disintegration, or glacial action, or by man with his machines. Sand deposits are masses of weathered rock minerals, transported, collected, and sorted by the age-long action of streams.

From the earliest ages the formation of sand, silt, and clay has been going on through the breaking down of rocks. The changes involved in these processes are part physical and part chemical. All changes produced at or near the surface by atmospheric agents, which result in more or less complete disintegration and decomposition, are classed under the general term of "weathering." The action of physical agents alone, which results in the rock breaking down into smaller particles without destroying its identity, is termed "disintegration." On the other hand, the action of chemical agents destroys the identity of many of the minerals by the formation of new compounds, and this latter process is known as "decomposition." Silt and clay generally result from decomposition; and, as such chemical change has altered the character of the material (usually to its detriment so far as concrete purposes are concerned), that is one reason, but not the only reason, against permitting their presence in concrete sand.

Because of its hardness and resistance to chemical agents, quartz or silica is, therefore, the commonest mineral in sand. Other minerals such as feldspar, mica, etc., though originally present, because of their lesser resistance, have been more readily decomposed by the action of the elements; and by reason of their complete disintegration with resultant fine state of subdivision, have been removed by wind and water. Quartz crystals, therefore, remain as the most evident survivors of the parent rock and their survival is evidence of their desirable qualities for concrete.

115a. Crushed Stone and Screenings.—Crushed stone screenings, when free from clay, usually make excellent sand. These screenings ordinarily give a stronger mortar than natural sand but are likely to contain an undue amount of dust, especially when obtained from soft stone, and should be screened and washed to get rid of the finest particles before being used in mortar or concrete.

Crushed limestone makes a concrete of excellent early strength, provided the crushings are rerolled, as limestone breaks with a flat, scaly fracture, giving particles that are structually weak and that are very hard to compact in the manner necessary to give an impervious concrete. For work exposed to water this point is of great importance.

115b. Sea Sand.—Sea sand is usually well suited for use as fine aggregate for concrete, so far as structure, mineral composition, and cleanness are concerned. It is, however, usually of such fineness that its use is inadvisable if undiluted by coarser particles. Saline deposits on the grains, when derived from pure sea water, should not be of a nature detrimental to concrete. It is unwise to take such sands close to tide limits, as the newer sands close to water teem with minute organic life.

116. Requirements of Fine Aggregate as to Shape and Size of Particles.— It is exceedingly difficult in choosing a fine aggregate for concrete work to balance all considerations. Time is a factor of utmost importance in all construction operations. Therefore, where delays would be entailed by the selection of one sand, the qualities of which are superior to those of another sand that is more readily obtained, it is more than probable that considerations of superior quality will have little weight. It is unfortunately true that regardless of all that has become known in regard to the importance of sands, their quality will be generally disregarded in favor of cheapness or convenience until engineers and owners demand and insist upon concretes of proper quality and refuse payment for those not coming up to the desired standard.

Usual specifications for concrete sands permit of little discrimination on the part of the supervising engineer, however conscientious he may be. Provision that the sand shall be "clean, sharp, and coarse" means nothing, as no standards are defined as comparisons and the determination is left solely to the judgment of individuals oftentimes quite incompetent and unskilled.

Sharpness as a quality requirement for sand is archaic. It has little or no definite meaning; and rarely are two individuals agreed as to how sharpness should be determined. If it were but remembered that all natural sands are water borne and water worn, with inevitable rounding of grains, the fallacy of "sharpness," whatever its interpretation, as a standard of quality in natural sands, would be evident.

Cleanness in sands is most important, for reasons before given. Not all dirt or coatings on sand are detectable, short of laboratory procedures; and unfortunately, much sand is judged as to cleanliness by rubbing in a hand that itself is usually none too clean, the fitness of the sand being judged by the deposit it leaves behind. Judging a sand in this way without supplemental tests betokens ignorance, or carelessness, or both. Cleanness is a desirable quality, but it should be judged by adequate tests, not by such haphazard methods as the foregoing.

Coarseness in sands, as opposed to excessive fineness, is a desirable quality, but coarseness alone, especially if judged without standards, is no criterion of fitness for use in concrete. Coarse sands have less surface area than have fine sands for a given unit volume, thus requiring less cement and being more readily coated. Such a requirement, if properly judged, is therefore advantageous.

117. Organic Contamination of Sand.—Colloidal or other organic coatings on sand are not difficult of detection before use. A good test method for this purpose, now known as the Abrams-Harder test, has been developed at Lewis Institute under the auspices of the Association of American Portland Cement Manufacturers. Briefly, it is carried out by digesting a sample of sand in a 2% solution of caustic soda. The resulting color of the fluid is an approximate indication of the quantity presence of organic matter in any sand. Color plates and directions for this test may be obtained on application to the Portland Cement Association at its several offices.

118. Tests for Quality of Sands.—Safe and advantageous procedure in choosing sand for concrete is:

1. Determine its cleanness by shaking a sample with water in a bottle; and also by the color test for organic impurities.
2. Determine its average granulometric analysis, giving preference to coarse rather than to fine sand.
3. For the sand and stone chosen, approximate proportions for the mix such as will give a dense mixture. (This is not always permitted under the specifications governing the work.)
4. Check these proportions (or the specific proportions), as well as the quality of materials, by strength or other tests on actual samples of concrete.
5. Check all shipments of sand with regard to cleanness, as in paragraph 1.

119. Requirements of Coarse Aggregate as to Shape and Size of Particles.—Since stone is one of the strongest, if not the strongest constituent of concrete, the greater the percentage of stone in any unit volume (*i.e.*, the nearer concrete actually approaches natural stone in strength and density) the stronger is the concrete. It follows, then, other things being equal, that the larger the quantity of stone, the stronger will be the concrete, since each piece of stone has greater mass density than would its components unless compacted and united by Nature's unapproachable processes.

There are, however, certain limitations as to size of stone imposed by certain classes of work. In reinforced work, the plastic concrete must fit itself closely around the reinforcing metal, so that 1 to 1½ in. is the greatest diameter of particle that experience demonstrates is advisable to use.

Concrete of this character obviously requires more cement than would concrete using larger stone, since the stone surface to be coated is greater. In mass work, on the other hand, crushed stone of 2½ to 3 in. diameter may be advantageously employed, with less cement. For these reasons, if for no others, richer mixtures are specified in reinforced work and leaner mixtures in mass work. It should be borne in mind, however, that size of stone is not alone the determining factor in this regard, but that grading of stone and size and grading of sand is of even more importance as influencing the quantity of cement required, with a corresponding effect on the quality of concrete.

Plums are large stone, 5 in. or more in least diameter, thrown into plastic mass concrete, largely with the object of using them as cheap space-fillers. Their use is also to be recommended for the reasons before given, provided that the plums themselves are of the proper quality of stone and that they are not of such size as to cut through the concrete section. A safe rule to follow in the use of plums is that they shall be of a maximum size such that not less than 6 in. of concrete shall intervene between them and the forms at any point. In using very large plums, this thickness of interveing concrete should be materially increased.

The shape of particle of large aggregates is of relatively little importance. Cleanliness, grading, and character of rock have far greater influence on the concrete than has angularity or roundness of particle.

120. Impurities in Aggregates.—In order that cement may adhere to sand grains and to particles of coarse aggregate, each grain or particle must bear no coating such as would prevent either proper chemical action between cement and water, or a proper bond between cement and aggregates.

Clay and silt are impurities of most frequent occurrence in sand and gravel. Each of these impurities cause injury to mortar or concrete not only when it exists as a coating on the sand or gravel particles, but is equally unde-

sirable when it occurs in such amounts, or so unequally distributed, that its extremely fine grains "ball up" and stick together when wetted, so as to remain in lumps in the finished mortar or concrete. If, however, the particles of these impurities are distributed so that they do not bind together on the addition of water; and if they are not contaminated by organic matter, experiments have shown that with sand that is not too fine, no serious harm results in lean mortars and concretes from their presence to the extent of from 10 to 15 %. In fact, either clay or silt are often found beneficial as they increase the density by filling some of the voids, thus increasing the strength and water-tightness besides making the mortar or concrete work smoothly. In rich mortars and concretes the density and consequently the strength is lowered by even slight additions of clay or silt as the cement furnishes all the fine material that is required.

A coating of organic matter, such as loam on sand grains, appears not only to physically prevent the cement from adhering but also to affect it chemically. In some cases a quantity of organic matter so small that it cannot be detected by the eye and is only slightly disclosed by chemical tests has prevented the mortar or concrete from reaching any appreciable strength. Tannic acid, colloidal sewage, manure, sugar, tobacco juice are instances of organic contamination destructive to concrete. All organic contaminations are detectable by the Abrams-Harder test before referred to.

Mica in sand or stone is objectionable because of its low mechanical strength and its laminated scaly structure. Even a small amount of the impurity in sand may seriously reduce the strength of a mortar or concrete. Mica is especially injurious in sands for concrete surface work as the scaly flakes cause the surface to dust and peel. Mica above 1 % is objectionable. It is detectable visually, but there is no exact method in use to determine its percentage presence.

Mica schist is totally unfit for use as large aggregate, both because of the foregoing reasons and also because of its rapid decomposition on exposure to air. The presence and character of this is detectable by observation.

Iron pyrites or *fool's gold*—a bright, yellow substance with metallic luster—is chemically iron sulphide (Fe_2S). This is a very common impurity in stone; and its undesirability lies in its ready oxidation in the presence of water with formation of sulphuric acid (H_2SO_4), which latter readily attacks the cement of concrete with disastrous consequences.

Some sand deposits also contain unoxidized iron sulphide, though such deposits are an exception.

Finely powdered dust present in crushed stone screenings causes approximately the same effect upon the strength of mortar or concrete as does the presence of silt or clay in like quantities. It is essential for the best work that this dust be removed by screening and washing, in the same manner that silt is removed from sand and gravel, though it may later be used advantageously in known quantities by recombination.

121. Water.—The water used in mixing mortar or concrete should be free from oil, acids, alkalies, or vegetable matter, and should be of a quality fit for drinking purposes. The presence of oils is easily detected by the characteristic iridescent surface film. Vegetable matter can sometimes be detected by observing floating particles, or by turbidity. Chemical determinations such as the Abrams-Harder test are better and more certain.

Tests of water for acidity or alkalinity may be made by means of litmus paper, procured at any chemist's. If blue litmus remains blue on immersing in the water, then the property is either neutral or alkaline; if the color changes to red, then the property is acidic. If there is a dangerous amount of acid present, the change in color will be very rapid. Likewise, if red litmus changes very quickly to blue, the water will be found to contain a dangerous amount of strong alkali. If the change of color is slow and faint in either test, the indication may be disregarded. A solution of phenol-phthalein is a delicate test for alkalinity.

Whenever a water does not appear satisfactory, its effect upon the strength and setting qualities of a cement should be determined by direct test on mixtures.

CONCRETE REINFORCEMENT

By H. E. Pulver

122. Types of Reinforcement.—The reinforcing steel in reinforced concrete construction is mostly in the form of rods, or bars, of round or square cross-section. These vary in size from ¼ to ⅜ in. for light floor slabs, up to 1¼ in. as a maximum size for heavy beams and columns. Both plain and deformed bars are used. With plain bars the adhesion between steel and concrete is depended upon to furnish the necessary bond strength. With deformed bars the usual adhesion is supplemented by a mechanical bond, the amount of this bond in any given case depending upon the shape of the bar. The adhesion of concrete to flat bars is less than for round or square bars, but the flat deformed bar possesses advantages over the other forms when used as hooping for tanks, pipes, and sewers where the reduced thickness of the bar allows the concrete section to have a greater effective depth for the same total thickness of concrete.

The Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, in their 1924 *Report*, states that the reinforcement bars shall conform to the areas and equivalent sizes shown in the following table:[1]

Size of bar, inches	Area, square inches	
	Round bar	Square bar
3/8	0.110	.....
1/2	0.196	0.250
5/8	0.306	.....
3/4	0.441	.....
7/8	0.601	.....
1	0.785	1.000
1 1/8	.....	1.265
1 1/4	.....	1.562

An approved deformed bar shall be one that will develop a bond at least 25 % greater than that of a plain round bar of equivalent cross-sectional area, the area of the deformed bar being determined by the minimum cross-section.

Wire fabric and expanded metal in various forms are used to a considerable extent in slabs, pipes, and conduits. These types of reinforcement are easy to place and are especially well adapted to resist temperature cracks and to prevent cracking of the concrete from impact or shock.

A number of combinations of forms are employed to a greater or lesser extent. These combinations are known as *systems*.

123. Surface of Reinforcement.—A rough surface on steel has a higher bond value for use in concrete than a smooth surface, consequently a thin film of rust on reinforcement should not cause its rejection. In fact in the case of cold-drawn wire which presents a very smooth surface,



Fig. 36.—Cold-twisted square bar.

a slight coating of rust is a decided advantage. Loose or scaly rust, however, should never be allowed. Reinforcement in this state of corrosion may be used if first cleansed with a stiff wire brush or given a bath of hydrochloric acid solution (consisting of 3 parts acid to 1 part water) and then washed in clean running water. Oiling and painting of reinforcing steel should not be permitted as its bonding value is greatly reduced thereby.

124. Quality of Steel.—Authorities differ as to the quality of steel to be used for reinforcement. Mild steel is the ordinary structural steel occurring in all structural shapes. High steel or steel of hard grade has a greater percentage of carbon than mild steel and is also known as high-carbon or high elastic-limit steel.

Brittleness is to be feared in high steel, although this quality is not so dangerous when the metal is used in heavy reinforced-concrete members—for example, in heavy beams or slabs—as the concrete to a large extent absorbs the shocks and protects the steel. All high steel should be carefully inspected and tested in order to prevent any brittle or cracked material from getting into the finished work. Steel of high elastic limit is seldom employed where plain bars are used.

Cold twisting increases the elastic limit and ultimate strength of mild-steel bars. The increase, however, is not definite, varying greatly with slight variations in the grade of the rolled steel. A square twisted bar is shown in Fig. 36.

125. Working Stresses.—The generally accepted working stress for mild steel is 16,000 lb. per sq. in. and 18,000 to 20,000 lb. per sq. in. for high steel and cold-twisted steel. A stress not greater than 16,000 lb. per sq. in. is recommended by the Joint Committee for all grades of steel.

[1] Most companies include the 1/4-in. round bar, area 0.049 sq. in., in their list of standard sizes of reinforcing bars.

The Joint Committee, in their 1924 *Report*, recommend the following working stresses in tension:

		Pounds per square inch
Billet-steel bars	Structural-steel grade	16,000
	Intermediate grade	18,000
	Hard grade	18,000
Rail-steel bars		16,000
Cold-drawn steel wire, spirals		Stress not calculated
Elsewhere		18,000

126.—Coefficient of Expansion.—The coefficient of expansion of steel is approximately 0.0000065 deg. F.

127. Modulus of Elasticity.—The modulus of elasticity of all grades and kinds of steel is about the same and is usually taken as 30,000,000 lb. per sq. in. in both tension and compression.

128. Steel Specifications.—The specifications for reinforcing steel in most general use appear to be those of the American Society for Testing Materials. The A.S.T.M. specifications for billet-steel and rail-steel concrete reinforcement bars and for cold-drawn steel wire for concrete reinforcement are given in Appendix *D*.

129. Factors Affecting Cost of Reinforcing Bars.—In order to insure minimum cost and prompt delivery of steel reinforcing bars, the steel schedule for a reinforced concrete structure should call for bars of as few different sizes and lengths as possible. Bars of odd-sixteenth sizes are seldom to be found in stock, and shipments from the mill on such sizes are likely to be very slow. Designers should always bear in mind this fact and arrange to use either round or square bars in ⅛-in. sizes, as stated in Art. 122. Wherever possible, steel lengths that do not vary greatly on the schedule should all be made equal, since an order calling for only a few different lengths will be put through the mill much more rapidly than one calling for many different lengths.

The following size extras for bars less than ¾-in. are standard with all mills and are the same for either round or square bars:

Size Extras for Rounds and Squares in Cents per 100 Lb.

¾-in. and larger	Base
⅝-in.	$0.10 extra
½-in.	0.20 extra
⅜-in.	0.40 extra
¼-in.	1.00 extra

Lengths less than 10 ft. should be avoided, if possible, as they are subject to the following cutting extras, whether sheared or hot sawed:

Cutting to lengths	Per 100 lb.
Of 120 in. and over	No charge
Over 60 in. to but not including 120 in.	$0.05
Over 48 to 60 in. inclusive	0.10
Over 24 to 48 in. inclusive	0.15
Over 12 to 24 in. inclusive	0.20
Of 12 in. and less; extra will be furnished on application but will not be less than	0.40

All orders calling for less than 2000 lb. of the same size and shape are subject to the following extras:

Quantities less than	Per 100 lb
2000 but not less than 1000 lb.	$0.20
1000 lb.	0.50

Whether or not quantity differentials or cutting extras apply, there will be an extra charge for cutting less than 2000 lb. of any size to a specified length, regardless of the total tonnage of the size ordered, regardless of what the length may be, and regardless of the exact quantity shipped, as follows:

Less than	Per 100 lb.
2000 to 1500 lb.	$0.10
1500 to 1000 lb.	0.20
1000 to 500 lb.	0.40
500 lb.	0.60

130. Deformed Bars.—There are many kinds of deformed bars on the market at the present time. Fig. 37 illustrates a number of these bars.

Most deformed-bar manufacturers will roll for stock the following sizes only:

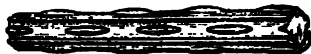
Round Bars.—¼, ⅜, ½, ⅝, ⅞, and 1 in.

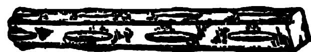
Square Bars.—½, 1, 1⅛, and 1¼ in.

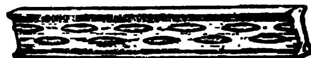
All other sizes will be considered as special.



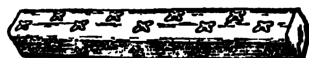
Diamond bar







Havemeyer bars



nland bar

Corrugated bars

Rib bar



American bars

'ig. 37.—Types of deformed bars.

Deformed bars conform in cross-sectional areas to the areas recommended by the Joint Committee in their 1924 *Report*. The following table gives the areas and their equivalents:

Area, square inches	Equivalent to	Weight per foot, pounds
0 049	¼ in. round	0 17
0.110	⅜ in. round	0.38
0 196	½ in round	0.67
0 250	½ in. square	0.85
0 307	⅝ in. round	1.05
0 442	¾ in. round	1.51
0.601	⅞ in. round	2.05
0 785	1 in. round	2.68
1.000	1 in. square	3.43
1.266	1⅛ in. square	4 35
1.563	1¼ in. square	5 35

131. Wire Fabric.—This material is used to a considerable extent for floors, roofs, walls, vaults, pavement, etc., and has been found to possess many valuable qualities. Wire fabric is made of steel wires crossing generally at right angles and secured at the intersections. The heavier wires run lengthwise and are called carrying wires; the lighter ones cross these and are called distributing or tie wires. The wires may be woven or welded together. One distinct advantage in the use of fabric is that it preserves uniform spacing of the steel.

The manner of securing the intersections of wire fabric has given rise to a number of different types, several of the principal ones of which are given in the articles following.

The steel-wire gage adopted as standard for all steel wire upon recommendation of the United States Bureau of Standards is given in the table on p. 1006:

Steel Wire Gage

Diameter, inches	Steel wire gage[1]	Diameter, inches	Area, square inches	Pounds per foot	Pounds per mile	Feet per pound
1/2	..	0.5000	0.19635	0.6668	3,521.0	1.500
....	7/0	0.4900	0.18857	0.6404	3,381.0	1.562
15/32	...	0.46875	0.17257	0.5861	3,094.0	1.706
...	6/0	0.4615	0.16728	0.5681	2,999.0	1.760
7/16	...	0.4375	0.15033	0.5105	2,696.0	1.959
....	5/0	0.4305	0.14556	0.4943	2,610.0	2.023
13/32	...	0.40625	0.12962	0.4402	2,324.0	2.272
....	4/0	0.3938	0.12180	0.4136	2,184.0	2.418
3/8	...	0.3750	0.11045	0.3751	1,980.0	2.666
....	3/0	0.3625	0.10321	0.3505	1,851.0	2.853
11/32	...	0.34375	0.092806	0.3152	1,664.0	3.173
....	2/0	0.3310	0.086049	0.2922	1,543.0	3.442
5/16	..	0.3125	0.076699	0.2605	1,375.0	3.839
...	0	0.3065	0.073782	0.2506	1,323.0	3.991
...	1	0.2830	0.062902	0.2136	1,128.0	4.681
9/32	..	0.28125	0.062126	0.2110	1,114.0	4.74
...	2	0.2625	0.054119	0.1838	970.4	5.441
1/4	..	0.2500	0.049087	0.1667	880.2	5.999
...	3	0.2437	0.046645	0.1584	836.4	6.313
...	4	0.2253	0.039867	0.1354	714.8	7.386
7/32	..	0.21875	0.037583	0.1276	673.9	7.835
...	5	0.2070	0.033654	0 1143	603.4	8.750
...	6	0.1920	0.028953	0.09832	519.2	10.17
3/16	..	0.1875	0.027612	0.09377	495.1	10.66
...	7	0.1770	0.024606	0.08356	441.2	11.97
...	8	0.1620	0 020612	0 07000	369.6	14.29
5/32	..	0.15625	0.019175	0.06512	343.8	15.36
...	9	0.1483	0 017273	0.05866	309.7	17.05
1/8	10	0.1350	0.014314	0 04861	256.7	20.57
...	..	0.125	0.012272	0.04168	220.0	24.00
...	11	0.1205	0.011404	0.03873	204.5	25.82
...	12	0.1055	0.0087417	0.02969	156.7	33.69
3/32	..	0.09375	0.0069029	0.02344	123.8	42.66
	13	0.0915	0.0065755	0.02233	117.9	44.78
	14	0.0800	0.0050266	0.01707	90.13	58.58
	15	0.0720	0.0040715	0.01383	73.01	72.32
	16	0.0625	0.0030680	0.01042	55.01	95.98
	17	0.0540	0.0022902	0.007778	41.07	128.60

[1] Formerly called the "American Steel & Wire Co.'s Gage."

National Steel Fabric Company

National Steel Fabric Standard Styles

Suggested uses	Style	Spacing, inches: Longitudinal	Spacing, inches: Transverse	Gage of wire: Longitudinal	Gage of wire: Transverse	Sectional area square inch per linear foot: Longitudinal	Sectional area square inch per linear foot: Transverse	Weight per 100 sq. ft., pounds
Cement gun work, composition floors, fireproofing, etc.	AA 1414	2	2	14	14	0.030	0.030	21.1
	AA 1212	2	2	12	12	0.052	0.052	36.8
	TT 1414	3	3	14	14	0.020	0.020	14.2
	TT 1212	3	3	12	12	0.035	0.035	24.7
	TT 1010	3	3	10	10	0.057	0.057	40.5
	BB 1414	4	4	14	14	0.015	0.015	10.8
	BB 1313	4	4	13	13	0.020	0.020	14.1
	BB 1212	4	4	12	12	0.026	0.026	18.7
	BB 1010	4	4	10	10	0.043	0.043	30.6
Cement gun work, levee lining, etc.	BB 88	4	4	8	8	0.062	0.062	44.1
	BB 66	4	4	6	6	0.087	0.087	61.9
	BB 44	4	4	4	4	0.120	0.120	85.3
Temperature reinforcement, driveways, sidewalks, etc.	CC 1212	6	6	12	12	0.017	0.017	12.7
	CC 1010	6	6	10	10	0.029	0.029	20.7
	CC 99	6	6	9	9	0.035	0.035	25.1
	CC 66	6	6	6	6	0.058	0.058	42.0
Slab reinforcement, retaining walls, etc.	AH 711	2	16	7	11	0.148	0.008	54.8
	AH 610	2	16	6	10	0.174	0.011	64.7
	AH 510	2	16	5	10	0.202	0.011	74.6
	AH 49	2	16	4	9	0.239	0.013	88.5
	AH 38	2	16	3	8	0.280	0.015	103.6
	TH 711	3	16	7	11	0.098	0.009	38.1
	TH 610	3	16	6	10	0.116	0.011	45.1
	TH 510	3	16	5	10	0.135	0.011	51.8
	TH 49	3	16	4	9	0.160	0.013	61.4
	TH 38	3	16	3	8	0.187	0.015	72.0
	TH 28	3	16	2	8	0.217	0.015	82.6
	TH 17	3	16	1	7	0.252	0.018	96.2
	TH 06	3	16	0	6	0.295	0.022	112.9
	BH 711	4	16	7	11	0.074	0.008	29.7
	BH 610	4	16	6	10	0.087	0.011	35.2
	BH 510	4	16	5	10	0.101	0.011	40.4
	BH 49	4	16	4	9	0.120	0.013	47.9
	BH 38	4	16	3	8	0.140	0.015	56.1
	BH 28	4	16	2	8	0.162	0.015	64.3
Slab reinforcement, fireproofing, etc.	BF 1212	4	12	12	12	0.026	0.009	12.6
	BF 1112	4	12	11	12	0.034	0.009	15.5
	BF 1012	4	12	10	12	0.043	0.009	18.6
	BF 912	4	12	9	12	0.052	0.009	21.8
	BF 812	4	12	8	12	0.062	0.009	25.5
	BF 711	4	12	7	11	0.074	0.011	30.7
	BF 610	4	12	6	10	0.087	0.014	36.5
	BF 510	4	12	5	10	0.101	0.014	41.6
	BF 49	4	12	4	9	0.120	0.017	49.4
Beam wrapping, fireproofing, etc.	BD 1313	4	8	13	13	0.020	0.010	10.6
	BD 1212	4	8	12	12	0.026	0.013	14.1
	BD 1112	4	8	11	12	0.034	0.013	17.0
	BD 1012	4	8	10	12	0.043	0.013	20.3
Concrete pipe, etc.	BD 912	4	8	9	12	0.052	0.013	23.4
	BD 812	4	8	8	12	0.062	0.013	27.0
	BD 711	4	8	7	11	0.074	0.017	32.7

Note: The "Style" letters and numerals refer respectively to the spacing of wires and to the gage of wires; for instance, "BD" means 4-in. spacing of longitudinal wires and 8-in. spacing of transverse wires, and "1112" means No. 11 gage longitudinal wires and No. 12 gage transverse wires.

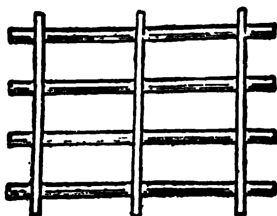


Fig. 38.—Welded wire fabric.

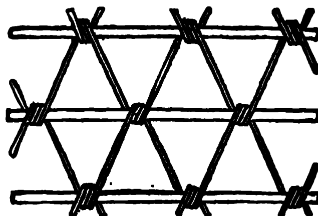


Fig. 39.—Triangle-mesh wire fabric.

American Steel and Wire Company

Triangle Mesh Woven Wire Concrete Reinforcements

Style No.	Number and gage of wires each, longitudinal, A. S. & W. Co.'s steel-wire gage	Sectional area longitudinals, square inch per foot width	Total effective longitudinal sectional area, square inch per foot width	Approx. weight, pounds per 100 sq. ft.
Longitudinals spaced 4 in. Cross wires No. 14-gage, spaced 4 in.				
032	1—No. 12 gage	0.026	0.032	22
040	1—No. 11 gage	0.034	0.040	25
049	1—No. 10 gage	0.043	0.049	28
058	1—No. 9 gage	0.052	0.058	32
068	1—No. 8 gage	0.062	0.068	35
080	1—No. 7 gage	0.074	0.080	40
093	1—No. 6 gage	0.087	0.093	45
107	1—No. 5 gage	0.101	0.107	50
126	1—No. 4 gage	0.120	0.126	57
146	1—No. 3 gage	0.110	0.146	65
153	1—¼ in.	0.147	0.153	68
168	1—No. 2a gage	0.162	0.168	74
180'	2—No. 6 gage	0.174	0.180	78
208	2—No. 5 gage	0.202	0.208	89
245	2—No. 4 gage	0.239	0.245	103
267	3—No. 6 gage	0.261	0.267	111
287	3—No. 5½ gage	0.281	0.287	119
309	3—No. 5 gage	0.303	0.309	128
336	3—No. 4½ gage	0.330	0.336	138
365	3—No. 4 gage	0.359	0.365	149
395	3—No. 3½ gage	0.389	0.395	160
Longitudinals spaced 4 in. Cross wires No. 14-gage, spaced 8 in.				
036P	1—No. 12 gage	.....	0.036	17
044P	1—No. 11 gage	.....	0.044	20
053P	1—No. 10 gage	.....	0.053	24
062P	1—No. 9 gage	.....	0.062	27
072P	1—No. 8 gage	.....	0.072	31
084P	1—No. 7 gage	.....	0.084	35
097P	1—No. 6 gage	.....	0.097	40
Longitudinals spaced 4 in. Cross wires No. 12½-gage, spaced 8 in.				
041R	1—No. 12 gage	.....	0.041	21
049R	1—No. 11 gage	.....	0.049	24
058R	1—No. 10 gage	.....	0.058	28
067R	1—No. 9 gage	.....	0.067	31
077R	1—No. 8 gage	.....	0.077	35
089R	1—No. 7 gage	.....	0.089	40
102R	1—No. 6 gage	.....	0.102	44

Length of rolls: 150 ft., 200 ft., and 300 ft.

Widths: approximately 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, and 56 in.

Note: Material may be furnished either plain or galvanized. Unless otherwise specified, shipment will be made of material not galvanized.

Table Showing Sectional Areas of American Steel & Wire Company's Electrically Welded Wire Fabric

Area in Square Inches per Foot of Width for Various Spacing of Wires

American Steel & Wire Company's steel-wire gage number	Wire		Center-to-center spacing, inches											
	Diameter, inches	Area, square inches	2	3	4	5	6	7	8	9	10	12	14	16
0000	0.3938	0.12180	0.731	0.487	0.365	.....	0.244	.....	0.183	.....	...	0.122		
000	0.3625	0.10321	0.619	0.413	0.310	.....	0.206	.....	0.155	.....	.....	0.103		
00	0.3310	0.086049	0.516	0.344	0.258	.....	0.172	.....	0.129	.....	.....	0.086		
0	0.3065	0.073782	0.443	0.295	0.221	0.177	0.148	0.126	0.111	0.098	0.089	0.074	0.063	0.055
1	0.2830	0.062902	0.377	0.252	0.189	0.151	0.126	0.108	0.094	0.084	0.075	0.063	0.054	0.047
2	0.2625	0.051119	0.325	0.216	0.162	0.130	0.108	0.093	0.081	0.072	0.065	0.054	0.046	0.041
3	0.2437	0.046645	0.280	0.187	0.140	0.122	0.093	0.080	0.070	0.062	0.056	0.047	0.040	0.035
4	0.2253	0.039867	0.239	0.159	0.120	0.096	0.080	0.068	0.060	0.053	0.048	0.040	0.034	0.030
5	0.2070	0.033654	0.202	0.135	0.101	0.081	0.067	0.058	0.050	0.045	0.040	0.034	0.029	0.025
6	0.1920	0.028953	0.174	0.116	0.087	0.069	0.058	0.050	0.043	0.039	0.035	0.029	0.025	0.022
7	0.1770	0.024606	0.148	0.098	0.074	0.059	0.049	0.042	0.037	0.033	0.030	0.025	0.021	0.018
8	0.1620	0.020612	0.124	0.082	0.062	0.049	0.041	0.035	0.031	0.027	0.025	0.021	0.018	0.015
9	0.1483	0.017273	0.104	0.069	0.052	0.041	0.035	0.030	0.026	0.023	0.021	0.017	0.015	0.013
10	0.1350	0.014314	0.086	0.057	0.043	0.034	0.029	0.025	0.021	0.019	0.017	0.014	0.012	0.011
11	0.1205	0.011404	0.068	0.046	0.034	0.027	0.023	0.020	0.017	0.015	0.014	0.011	0.010	0.009
12	0.1055	0.0087417	0.052	0.035	0.026	0.021	0.017	0.015	0.013	0.012	0.010	0.009	0.007	0.007
13	0.0915	0.0065755	0.039	0.026	0.020	0.016	0.013	0.011	0.010	0.009	0.008	0.007	0.006	0.005
14	0.0800	0.0050266	0.030	0.020	0.015	0.012	0.010	0.009	0.008	0.007	0.006	0.005	0.004	0.004

American Steel & Wire Company's Electric-weld Fabric in Rolls or Sheets
For Concrete Floors and Miscellaneous Construction

Style number	Spacings of wires, inches		Gage number		Section areas, square inches per foot		Weight per 100 sq. ft.
	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	
216-17	2	16	1	7	0.377	0.018	130
216 28	2	16	2	8	0.325	0.015	119
216 38	2	16	3	8	0.280	0.015	104
216 49	2	16	4	9	0.239	0.013	89
216-510	2	16	5	10	0.202	0.011	75
216 610	2	16	6	10	0.174	0.011	65
216 711	2	16	7	11	0.148	0.008	55
216 812	2	16	8	12	0.124	0.007	46
316 17	3	16	1	7	0.252	0.018	96
316 28	3	16	2	8	0.216	0.015	83
316 38	3	16	3	8	0.187	0.015	72
316 49	3	16	4	9	0.159	0.013	61
316-510	3	16	5	10	0.135	0.011	52
316-610	3	16	6	10	0.116	0.011	45
316-711	3	16	7	11	0.098	0.009	38
316 812	3	16	8	12	0.082	0.007	32
416 28	4	16	2	8	0.162	0.015	64
416 38	4	16	3	8	0.140	0.015	56
416 49	4	16	4	9	0.120	0.013	48
416 510	4	16	5	10	0.101	0.011	40
416 610	4	16	6	10	0.087	0.011	35
416 711	4	16	7	11	0.074	0.009	30
412 812	4	12	8	12	0.062	0.009	26
412 912	4	12	9	12	0.052	0.009	22
412 1012	4	12	10	12	0.043	0.009	19
412 1212	4	12	12	12	0.026	0.009	13
48 1214	4	8	12	14	0.026	0.008	12
48 1313	4	8	13	13	0.020	0.010	11
66 66	6	6	6	6	0.058	0.058	42
66 77	6	6	7	7	0.049	0.049	36
66 88	6	6	8	8	0.041	0.041	30
66-99	6	6	9	9	0.035	0.035	25
66-1010	6	6	10	10	0.029	0.029	21
66 1212	6	6	12	12	0.017	0.017	13
44 44	4	4	4	4	0.120	0.120	85
44 66	4	4	6	6	0.087	0.087	62
44 77	4	4	7	7	0.074	0.074	53
44 88	4	4	8	8	0.062	0.062	44
44 1010	4	4	10	10	0.043	0.043	31
44 1212	4	4	12	12	0.026	0.026	19
44 1313	4	4	13	13	0.020	0.020	14
44 1414	4	4	14	14	0.015	0.015	11
33-1010	3	3	10	10	0.057	0.057	41
33-1212	3	3	12	12	0.035	0.035	25
33-1414	3	3	14	14	0.020	0.020	14
24-1314	2	4	13	14	0.039	0.015	19
22-1212	2	2	12	12	0.052	0.052	37
22-1313	2	2	13	13	0.039	0.039	28
22-1414	2	2	14	14	0.030	0.030	21

WICKWIRE SPENCER STEEL CORPORATION

STANDARD SIZES—CLINTON WELDED FABRIC

Style No.	Spacing of wires		Size wires W & M gauge		Sectional area of steel per foot width, square inch		Weight, per 100 sq. ft., pounds	Standard rolls	
	Londitudinal, inches	Transverse, inches	Longitudinal, inches	Transverse, inches	Longitudinal, inches	Transverse, inches		Width, inches	Length, feet
*216- 28	2	16	2	8	0.325	0.015	119.4	60	150
*216- 38	2	16	3	8	0.280	0.015	103.6	60	150
*216- 49	2	16	4	9	0.230	0.013	88.5	60	150
*216- 510	2	16	5	10	0.202	0.011	74.6	60	150
*216- 610	2	16	6	10	0.174	0.011	64.7	60	200
*316 28	3	16	2	8	0.217	0.015	82.6	84	150
*316- 38	3	16	3	8	0.187	0.015	72.0	84	150
*316- 49	3	16	4	9	0.160	0.013	61.4	84	150
*316 510	3	16	5	10	0.135	0.011	51.8	84	150
*316 610	3	16	6	10	0.116	0.011	45.1	84	200
*416- 38	4	16	3	8	0.140	0.015	56.1	84	150
*416- 49	4	16	4	9	0.120	0.013	47.9	84	150
*416- 510	4	16	5	10	0.101	0.011	40.4	84	200
*416 610	4	16	6	10	0.087	0.011	35.2	84	200
*416- 711	4	16	7	11	0.074	0.009	29.7	84	200
*412 812	4	12	8	12	0.062	0.009	25.5	84	200
*412- 912	4	12	9	12	0.052	0.009	21.8	84	200
*412- 1012	4	12	10	12	0.043	0.009	18.6	100	300
*412 1212	4	12	12	12	0.026	0.009	12.6	100	400
412- 55	4	12	5	5	0.101	0.034	43.4	72	200
412- 66	4	12	6	6	0.087	0.029	41.6	72	200
412- 77	4	12	7	7	0.074	0.025	35.4	72	200
412- 88	4	12	8	8	0.062	0.021	29.6	72	200
*59 -1212	5	9	12	12	0.021	0.012	11.8	100	400
612- 06	6	12	0	6	0.148	0.029	65.3	72	†
612- 33	6	12	3	3	0.093	0.047	51.2	72	200
612- 44	6	12	4	4	0.080	0.040	43.8	72	200
612- 55	6	12	5	5	0.067	0.034	37.0	72	200
612 66	6	12	6	6	0.058	0.029	31.8	72	200
612- 77	6	12	7	7	0.049	0.025	27.0	72	200
22-1010	2	2	10	10	0.086	0.086	60.3	56	200
*22-1212	2	2	12	12	0.062	0.052	36.8	56	300
44- 44	4	4	4	4	0.120	0.120	85.3	84	150
44- 60	4	4	6	6	0.087	0.087	61.9	84	150
44- 88	4	4	8	8	0.062	0.062	44.1	84	200
66- 44	6	6	4	4	0.080	0.080	57.8	84	200
66 55	6	6	5	5	0.067	0.067	48.8	84	200
*66- 66	6	6	6	6	0.058	0.058	42.0	84	200
66- 77	6	..	7	7	0.049	0.049	35.7	84	200
*66- 88	6	6	8	8	0.041	0.041	30.0	84	200
*66-1010	6	6	10	10	0.020	0.020	20.7	96	300

* Denotes sizes ordinarily carried in stock. † Shipped only in flat sheets.

132. Expanded Metal.—Expanded metal (Fig. 40) is one of the oldest forms of sheet reinforcement. It is formed by slitting a sheet of soft steel and then expanding the metal in a

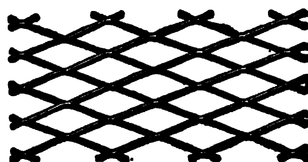


FIG. 40.—Expanded metal.

direction normal to the axis of the sheet. The principal advantages claimed for this type of reinforcement are the following: (1) an increased ultimate strength and high elastic limit for low-carbon steel when the diamond-shaped meshes are formed by cold drawing the metal; (2) a mechanical bond with the surrounding concrete; (3) great efficiency in the carrying of concentrated loads due to the obliquity of the strands; (4) an increased ductility because of the fact that the diamonds or quadrilaterals tend to close under severe loading; (5) a greater slab strength as the effect of closing up of the diamonds is to introduce a compression into the concrete at the lower part of the slab. Expanded metal and other sheet metal is made according to the U. S. Standard gage which differs but slightly from the steel-wire gage given on page 1006.

The details of several typical kinds of expanded metal are given in the following tables. No attempt has been made to include all of the kinds of expanded metal on the market in this article.

THE CONSOLIDATED EXPANDED METAL COMPANY

STANDARDS FOR "STEELCRETE" EXPANDED METAL

Designation of mesh	Effective sectional area square inch per foot width	Approx. weight per square foot, pound	Standard width of sheets, feet-inches	Square foot in a standard sheet of various lengths				Sheets in a standard bundle
				8 ft.	10 ft.	12 ft.	16 ft.	
3-13-075	0.075	0.25	6-4	50.67	63.33	76.00	101.33	10
3-13-10	0.10	0.31	7-0	56.00	70.00	84.00	112.00	7
3-13-125	0.125	0.42	5-8	45.33	56.67	68.00	90.67	7
3-9-15	0.15	0.51	7-0	56.00	70.00	84.00	112.00	5
3-9-175	0.175	0.60	6-0	48.00	60.00	72.00	96.00	5
3-9-20	0.20	0.68	5-3	42.00	52.50	63.00	84.00	5
3-9-25	0.25	0.85	4-2½	33.67	42.08	50.50	67.33	5
3-9-30	0.30	1.02	7-0	56.00	70.00	84.00	112.00	2
3-9-35	0.35	1.19	6-0	48.00	60.00	72.00	96.00	2
3-4-40	0.40	1.36	4-7	36.67	45.83	55.00	73.33	2
3-4-45	0.45	1.53	4-1	32.67	40.83	49.00	65.33	2
3-4-50	0.50	1.70	7-4	58.67	73.33	88.00	117.33	2
3-4-55	0.55	1.87	6-8	53.33	66.67	80.00	106.67	2
3-4-60	0.60	2.01	6-1½	49.00	61.25	73.50	98.00	2

NOTE: All the above sizes are furnished in a standard diamond 8-in. length and approximately 3-in. width. All sizes are furnished in stock lengths 8, 12, and 16 ft. In addition all sizes from 3-13-075 to 3-9-35, inclusive, are furnished in stock lengths of 10 ft.

EXTRA HEAVY "STEELCRETE" EXPANDED METAL MANUFACTURED FROM $\frac{5}{16}$-IN. PLATE

Designation of mesh	Effective sectional area square inch per foot width	Approx. weight per square foot, pounds	Standard width of sheets, foot-inches	Square feet in a standard sheet of various lengths			Sheets in a standard bundle
				8 ft.	10 ft.	12 ft.	
3-1-75	0.75	2.74	5-5	43.33	54.17	65.00	1
3-1-100	1.00	3.63	4-0	32.00	40.00	48.00	1

NOTE: The above sizes are furnished in a diamond 8-in. length and approximately 3-in. width. Both sizes are furnished in stock lengths of 8, 10 and 12 ft. In addition, intermediate sectional areas will be furnished from stock lengths of 8 and 12 ft. The standard widths of sheets will be furnished for each case on application.

NORTHWESTERN EXPANDED METAL COMPANY'S STOCK SIZES AND WEIGHTS OF "ECONO" EXPANDED METAL

Reinforcing Meshes

Style	Size of mesh $a \times b$, inches	U. S. Standard gage number	Approximate size of strands $c \times d$, inches	Sectional area per 1 ft. of width, square inches	Weight, pounds per square foot	Widths of sheets short way of mesh	Lengths of sheets long way of mesh, feet
06-3	3 × 8	16	$\frac{1}{16} \times \frac{7}{64}$	0.06	0.20	6 ft	8 and 12
08-3	3 × 8	16	$\frac{1}{16} \times \frac{9}{64}$	0.08	0.27	6 ft.	8 and 12
10-3	3 × 8	13	$\frac{3}{32} \times \frac{1}{8}$	0.10	0.34	4 ft.	8, 10 and 12
125-3	3 × 8	13	$\frac{3}{32} \times \frac{5}{32}$	0.125	0.42	5 ft. 6 in.	8, 10 and 12
15-3	3 × 8	10	$\frac{9}{64} \times \frac{1}{8}$	0.15	0.51	7 ft.	8, 10 and 12
176-3	3 × 8	10	$\frac{9}{64} \times \frac{9}{64}$	0.176	0.60	6 ft.	8, 10 and 12
20-3	3 × 8	10	$\frac{9}{64} \times \frac{11}{64}$	0.20	0.68	5 ft 6 in.	8, 10 and 12
25-3	3 × 8	10	$\frac{9}{64} \times \frac{13}{64}$	0.25	0.85	4 ft. 3 in.	8, 10 and 12
30-3	3 × 8	10	$\frac{9}{64} \times \frac{1}{4}$	0.30	1.02	7 ft.	8, 10 and 12
35-3	3 × 8	10	$\frac{9}{64} \times \frac{19}{64}$	0.35	1.19	6 ft.	8, 10 and 12
40-3	3 × 8	7	$\frac{3}{16} \times \frac{1}{4}$	0.40	1.36	7 ft.	8, 10 and 12
45-3	3 × 8	7	$\frac{3}{16} \times \frac{9}{32}$	0.45	1.53	6 ft. 3 in.	8, 10 and 12
50-3	3 × 8	7	$\frac{3}{16} \times \frac{5}{16}$	0.50	1.70	5 ft. 9 in	8, 10 and 12
54-3	3 × 8	7	$\frac{3}{16} \times \frac{21}{64}$	0.54	1.83	5 ft. 6 in.	8, 10 and 12
60-3	3 × 8	7	$\frac{3}{16} \times \frac{3}{8}$	0.60	2.04	4 ft. 9 in	8, 10 and 12
65-3	3 × 8	7	$\frac{3}{16} \times \frac{13}{32}$	0.65	2.19	4 ft. 3 in.	8, 10 and 12
10-2¼	2¼ × 6	16	$\frac{1}{16} \times \frac{9}{64}$	0.10	0.34	5 ft.	8 and 12
15-2¼	2¼ × 6	13	$\frac{3}{32} \times \frac{11}{64}$	0.15	0.51	4 ft 9 in.	8, 10 and 12

GENERAL FIREPROOFING COMPANY'S STYLES AND SIZES OF EXPANDED METAL

Style	Size mesh short way of diamond, inches	Net section area per foot width, square inches	Approximate weight per square foot, pounds	Standard size sheets	
				Lengths long way of diamond	Widths short way of diamond
½ 20	½	0.20	0.68	6 ft., 8 ft.	3 ft., 4 ft., 6 in.
¾ 24	¾	0.24	0.80	6 ft., 8 ft.	4 ft. 4 in.
1½ 18	1½	0.18	0.60	6 ft, 8 ft.	4 ft. 3 in., 5 ft. 8 in.
3 08	3	0.08	0.27	6 ft, 8 ft., 10 ft., 8 in.	3 ft., 4 ft., 6 ft.
3 15	3	0.15	0.51	6 ft, 8 ft., 9 ft., 10 ft. 8 in.	3 ft. 6 in., 4 ft., 7 ft.
3 176	3	0.176	0.60	6 ft., 8 ft., 9 ft., 10 ft. 8 in.	3 ft., 4 ft, 6 ft.
3 -25	3	0.25	0.85	6 ft., 8 ft., 9 ft., 10 ft. 8 in.	4 ft 3 in., 5 ft. 8 in.
3 -25	3	0.35	1.19	6 ft., 8 ft., 9 ft., 10 ft 8 in	3 ft., 4 ft., 6 ft

National Steel Fabric Company's Standard Styles

Dimensions, Areas and Weights

Suitable uses	Style	Spacing, inches		Gage of wire		Sectional area, square inches per per linear foot		Weight per 100 sq. ft.
		Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	
	AA 1414	2	2	14	14	0.030	0.030	21.1
	AA 1212	2	2	12	12	0.052	0.052	36.8
Gunite	TT 1414	3	3	14	14	0.020	0.020	14.2
Stucco	TT 1212	3	3	12	12	0.035	0.035	24.7
Composition flooring	TT 1010	3	3	10	10	0.057	0.057	40.5
Fireproofing	BB 1414	4	4	14	14	0.015	0.015	10.8
Etc.	BB 1313	4	4	13	13	0.020	0.020	14.1
	BB 1212	4	4	12	12	0.026	0.026	18.7
	BB 1010	4	4	10	10	0.043	0.043	30.6
Gunite	BB 88	4	4	8	8	0.062	0.062	44.1
Canal lining	BB 66	4	4	6	6	0.087	0.087	61.9
Etc.	BB 44	4	4	4	4	0.120	0.120	85.3
	CC 1212	6	6	12	12	0.017	0.017	12 7
Sidewalks	CC 1010	6	6	10	10	0.029	0.029	20.7
Temperature reinforcing	CC 99	6	6	9	9	0.035	0.035	25 1
Ground floors	CC 88	6	6	8	8	0.041	0.041	29.9
Etc.	CC 77	6	6	7	7	0.049	0.049	35.7
	CC 66	6	6	6	6	0 058	0.058	42.0
	AH 711	2	16	7	11	0.148	0.008	54.8
Slab reinforcing	AH 610	2	16	6	10	0 174	0.011	64.7
Etc. (one direction only)	AH 510	2	16	5	10	0.202	0.011	74.6
	AH 49	2	16	4	9	0.239	0.013	88.5
	AH 38	2	16	3	8	0.280	0.015	103.6
	TH 711	3	16	7	11	0.098	0.009	38.1
	TH 610	3	16	6	10	0.116	0.011	45.1
	TH 510	3	16	5	10	0.135	0.011	51.8
Slab reinforcing	TH 49	3	16	4	9	0.160	0.013	61.4
Etc. (one direction only)	TH 38	3	16	3	8	0.187	0.015	72.0
	TH 28	3	16	2	8	0.217	0.015	82.6
	TH 17	3	16	1	7	0.252	0.018	96.2
	TH 06	3	16	0	6	0.295	0.022	112.9
	BD 1313	4	8	13	13	0.020	0.010	10.6
Beam wrapping	BD 1214	4	8	12	14	0.026	0.008	12.2
Fireproofing	BD 1212	4	8	12	12	0.026	0.013	14.1
Etc.	BD 1112	4	8	11	12	0.034	0.013	17.0
	BD 1012	4	8	10	12	0.043	0.013	20.3
	BD 912	4	8	9	12	0.052	0.013	23.4
Concrete pipe	BD 812	4	8	8	12	0.062	0.013	27.0
Etc.	BD 711	4	8	7	11	0.074	0.017	32.7
	BF 1212	4	12	12	12	0.026	0.009	12.6
	BF 1112	4	12	11	12	0.034	0.009	15.5
	BF 1012	4	12	10	12	0.043	0.009	18.6
Slab reinforcing	BF 912	4	12	9	12	0.052	0.009	21.8
Driveway	BF 812	4	12	8	12	0.062	0.009	25.5
Etc.	BF 711	4	12	7	11	0.074	0.011	30.7
	BF 610	4	12	6	10	0.087	0.014	36.5
	BF 510	4	12	5	10	0.101	0.014	41.6
	BF 49	4	12	4	9	0.120	0.017	49.4
	BH 711	4	16	7	11	0.074	0.008	29.7
Slab reinforcing	BH 610	4	16	6	10	0.087	0.011	35.2
Walls	BH 510	4	16	5	10	0.101	0.011	40.4
Etc.	BH 49	4	16	4	9	0.120	0.013	47.9
	BH 38	4	16	3	8	0.140	0.015	56.1
	BH 28	4	16	2	8	0.162	0.015	64.3

133. Rib Metal.—Rib metal is manufactured by the Truscon Steel Co. and consists of nine longitudinal ribs rigidly connected by light cross-members. It is made from a sheet of metal, flat on one side and corrugated on the other. Strips of the metal adjacent to the ribs are stamped out, and the sheet is drawn out into square meshes (Fig. 41). The standard

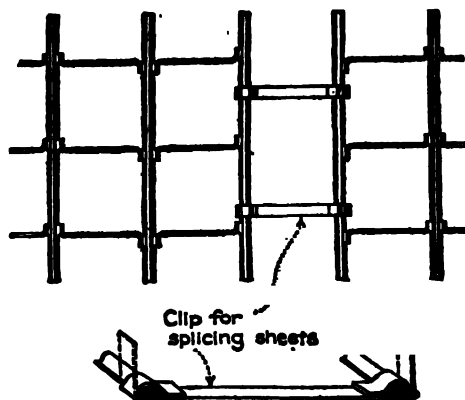


Fig. 41.—Rib metal.

sheets are manufactured with meshes of from 2 to 8 in. and in all lengths up to 18 ft. The properties of rib metal are given in the table which follows.

Rib Metal

Size number	Width of standard sheet, inches	Square feet per linear foot of standard sheet	Area per foot width, square inches	Weight per square foot, pounds
2	16	1.33	0.450	2.025
3	24	2.00	0.300	1.340
4	32	2.67	0.225	0.997
5	40	3.33	0.180	0.792
6	48	4.00	0.150	0.655
7	56	4 67	0.128	0.557
8	64	5 33	0 113	0.484
12	96	8.00	0.075	0.360

No. 12 rib metal is shipped unexpanded.
Area of one rib = 0.09 sq. in., nine ribs in one sheet.

134. Self-centering Fabrics.—Permanent centering fabrics (used mostly for reinforcement in concrete floor slabs resting on steel beams) are stiffened by rigid, deep ribs which do away with the use of slab forms. The mesh is made small enough to prevent ordinary concrete from passing through. The centering fabric is laid over the supports, the concrete is poured on top and the under side plastered. A simple brace along the middle of the slab span is sometimes required to give sufficient strength to the ribs until the concrete has set. The permanent centering fabrics may be obtained either in flat or segmental form.

A serious disadvantage in this type of construction is the difficulty of providing efficient fire protection on the under side of the fabric. Bond with the concrete is also likely to be insufficient.

Some of the types of self-centering fabrics are described in the following pages.

Hy-rib.—Hy-rib (Fig. 42) is a steel sheathing, stiffened by deep ribs formed from a single sheet of steel. It is controlled by the Truscon Steel Co. of Youngstown, Ohio.

Truscon ¾-in. Hy-rib is shipped eight sheets in a bundle. The sheets are furnished in standard lengths of 6, 8, 10, or 12 ft. in open-hearth or copper-bearing steel.

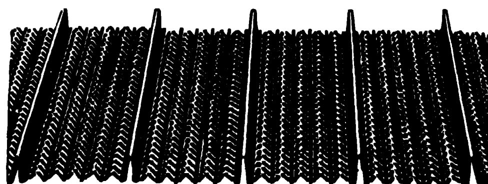


Fig. 42.—Truscon ¾-in. Hy-rib.

Properties ¾-in. Hy-rib

Weight per square foot, pounds	Height of ribs, inches center to center	Spacing of ribs, inches center to center	Number ribs per sheet	Width of sheet, inches	Cross-sectional area per foot width, square inches
0.58	¾	4	8	28	0 1172
0.68	¾	4	8	28	0.1407
0.78	¾	4	8	28	0 1642

Milcor.—The Corrugating Company, Milwaukee, Wis., makes a ¾-in. Milcor Stay-rib metal lath No. 3 i 24-in. widths and standard lengths of 4, 5, 6, 7, 8, 9, 10, 11, and 12 ft.

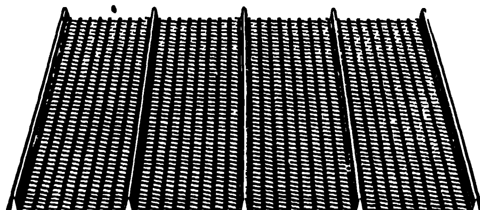


Fig. 43.—Milcor ¾-in. Stay-rib metal lath No. 3.

Milcor ¾-in. Stay-rib lath No. 3 is furnished in steel, "coppered metal," or Armco ingot iron. It is carried in stock, painted only, in the following weights:

Gage number, painted	Pounds per square feet
28	0 46
26	0.56
24	0 74

Furnished in galvanized steel in No. 28 gage only; *made to order* only, not carried in stock, weight as follows:

Gage number, galvanized	Pounds per square foot
28	0.53

Furnished in Armco ingot iron, painted, and carried in stock in two weights only, as follows:

Gage number, painted	Pounds per square foot
26	0.56
24	0.74

Self-sentering. "Self-sentering" (Fig. 44) is manufactured by the General Fireproofing Company, Youngstown, Ohio. It is made up of a series of heavy cold-drawn ribs, 1¹⁄₁₆ in. high, always spaced 3⅝ in. center to center,

connected by a form of expanded metal—all cut 29 in. wide by lengths of 4, 5, 6, 7, 8, 9, 10, 11, and 12 ft. Longer lengths up to 14 ft. furnished on special order. Self-sentering is made of Nos. 24, 26, and 28 gage metal.

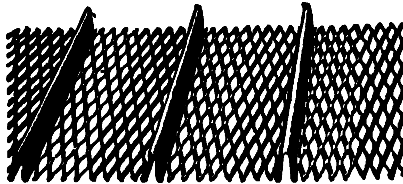


Fig. 44.—Self-sentering.

SELF-SENTERING WEIGHTS AND SECTIONAL AREAS

Painted weight per square foot, pounds	Effective sectional area per foot of width, square inches
0.55	0 167
0.65	0 193
0.75	0.223

Galvanized or Armco Self-sentering on mill shipment, minimum of 5 tons one weight and length.

Longspan.—The Northwestern Expanded Metal Company, Chicago, Ill., makes a ¾-in. "Longspan" rib lath. The ribs are spaced 4 8 in. on centers, and the lath is furnished in sheets 28.8 in. wide, in lengths of 8, 9, 10, 11, and 12 ft., and in weights of 0.5, 0.6, and 0.75 lb. per sq. ft., painted.

Ribplex.—"Ribplex," manufactured by the Berger Manufacturing Company, Canton, Ohio, is an expanded metal with ribs 4.8 in. on centers and ¾ in. high, made of painted steel only. Standard sheets are 24 in. wide and are carried in stock in 4, 5, 6, 7, 8, 9, 10, 11, and 12-ft. lengths. Sheets are made in Nos. 28, 26, and 24 gage. This material is furnished in weights of 0.50, 0.60, and 0.75 lb. per sq. ft.

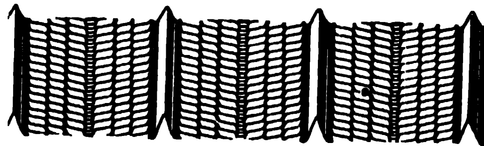


Fig. 45.—YPS ribplex.

Truss-V-Rib.—The Bostwick Steel Lath Company, Niles, Ohio, manufactures a "Truss-V-Rib" reinforced metal lath which is suitable for light concrete work without forms. This material is made from best open-hearth sheet metal. See the article on metal lath for a brief description of Truss-V-Rib properties.

YPS Ribplex.—The Youngstown Pressed Steel Company, Warren, Ohio, make a ¾-in. "Y. P. S. Ribplex" lath with ribs spaced 4.8 in. on centers. Standard sheets are 24 in. wide and are carried in stock in 4, 5, 6, 7, 8, 9, 10, 11, and 12-ft. lengths. This material is made in Nos. 28, 26, and 24 gage and weighs 50, 60, and 75 lb. per 100 sq. ft.

135. Reinforcing Systems.—There have been at various times many different types of concrete reinforcing systems placed on the market. In the following articles a few of these systems will be illustrated and described.

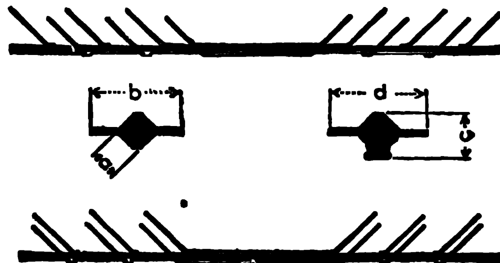


Fig. 46.—Kahn trussed bars.

Kahn System.—The Kahn trussed bar (Fig. 46), named for its inventor, is rolled with flanges, which are bent up to resist the shear in the beam. For continuous beams, inverted

bars are placed over the supports in the upper part of the beam, extending over the region of tension. Properties of Kahn trussed bars are shown in the following table:

KAHN TRUSSED BARS

Size $a \times b$, inches	Weight, pounds per foot	Area	Length of diagonals, inches	
			Standard	Special
Square section bars				
½ × 1½	1.4	0.41	12	(6), 8, (18)
¾ × 2⁵⁄₁₆	2.7	0.79	12, 24	8, (18), 30
New section bars				
1½ × 2¼	4.8	1.41	12, 24, 36	8, (18), 30
1¾ × 2¾	6.8	2.00	36	(24), 30, (48)
2 × 3½	10.2	3.00	36	(24), 30, (48)

NOTE.—All diagonals are sheared alternately except 6 in. diagonals which are sheared opposite. Lengths enclosed in parenthesis are special and are ordinarily available only for items of 5 tons or more.

What might be called the Kahn system is illustrated in Fig. 47. The collapsible column hooping is shown more in detail in Fig. 48. The hooping is shipped in the form of flat, circular

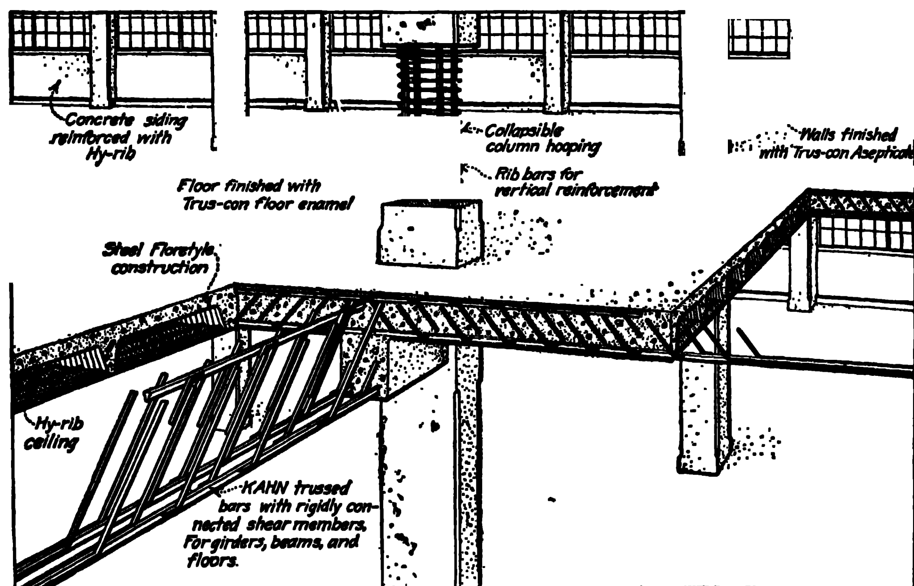


FIG. 47.—Kahn system.

coils of exact diameter and accurately spaced by means of special spacing bars. These coils spring automatically into a complete hooped column on cutting the small fastening wires. Rib bars (see Art. 130, p. 1005) are ordinarily used as vertical reinforcement in conjunction with the hooping.

The collapsible column hooping is shipped in bundles, coiled to the correct diameter, and with separate spacing bars, ready for assembling in the field. Sizes of wire for hooping: ¼, ⁵⁄₁₆, ⅜ and ½-in. diameter. Diameter of coils: 12 to 30 in. Pitch: 1½ to 3½ in.

Cummings System.—The Cummings system is shown in Fig. 49. U-shaped stirrups are used on the girder frame shown. They are shipped flat with the longitudinal reinforcement, but are bent up to an inclined position on the work. The rods are held together by means of a patented chair. In the Cummings hooped column, each hoop is securely attached to the

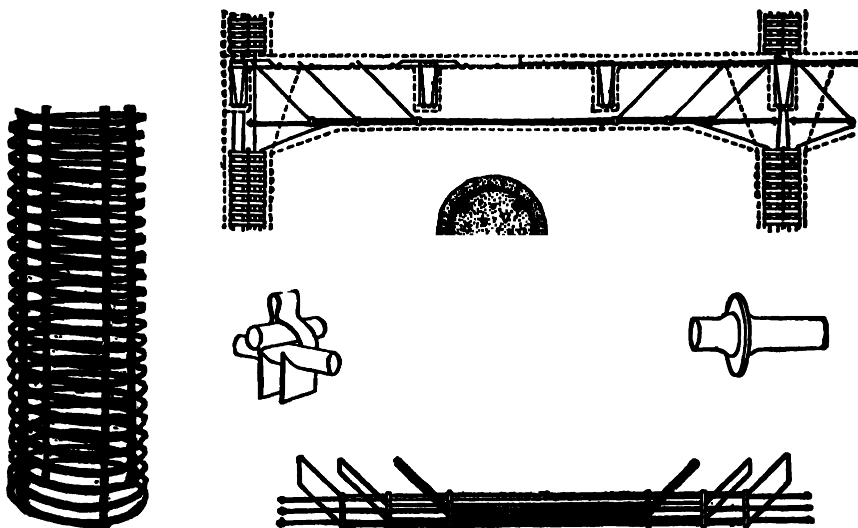


Fig. 48.—Kahn collapsible column hooping.

Fig. 49.—Cummings system.

upright rods. The hoops are made of flat steel, bent to a circle, with the ends riveted or welded together in such a manner that the ends of the hoops protrude at right angles to keep them the proper distance from the mold. Reinforcement of the Cummings system is manufactured and sold by the Electric Welding Co., Pittsburgh, Pa.

Unit System.—Figs. 50 and 51 show the unit system of reinforcing controlled by the American System of Reinforcing, Chicago, Ill. The girder frames are not stock frames but are built to meet the engineer's or architect's plans. Unit girder frames are provided with overlapping rods for continuous beams to reinforce against negative moment.

Corr System.—Corr-bar girder frames (Fig. 52) and shop fabricated spirals (Fig. 53) are furnished by the Kalman

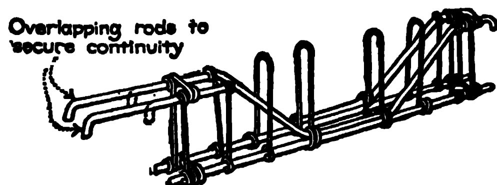


Fig. 50.—"Unit" frames.

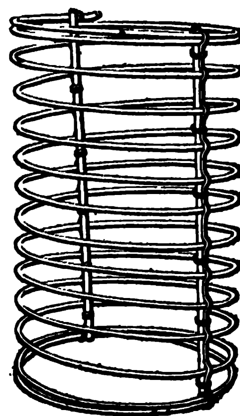


Fig. 51.—"Unit" spirals.

Steel Company, Chicago, Ill. As with the unit system, the girder frames are built to meet the engineer's or architect's plans. In the spiral reinforcement the spacing bars consist of two or—in large columns—four spacers made of T-section bars notched to receive the spiral. The spirals are made of cold-drawn wire and are furnished in any length, in diameters of 10 to 36 in., pitch 1 to 4 in., and of the following sizes of wire:

Gage	Diameter of wire, inches	Weight of wire, pounds per foot	Practical equivalent, inches	Gage	Diameter of wire, inches	Weight of wire, pounds per foot	Practical equivalent inches
7/0	0 4900	0 6404	½ round	0	0.3065	0.2506	5/16 round
5/0	0.4305	0 4943	7/16 round	3	0.2437	0.0466	¼ round
3/0	0.3625	0.3505	⅜ round				

Hennebique System.—One of the pioneers in concrete construction in Europe is Mr. Hennebique, in France, and the system which still bears his name is shown in Fig. 54.

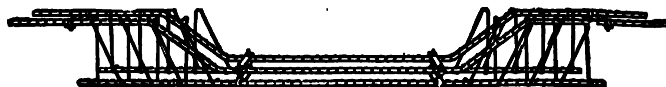


Fig. 52.—Corr-bar girder frame.

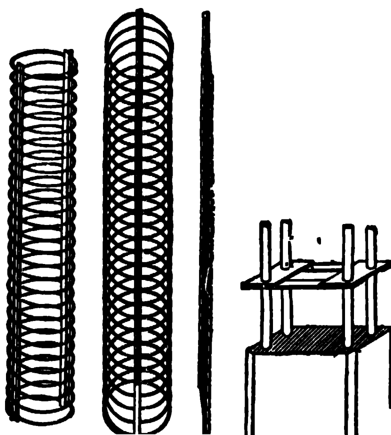


Fig. 53.—Corrugated Bar Co.'s spirals.

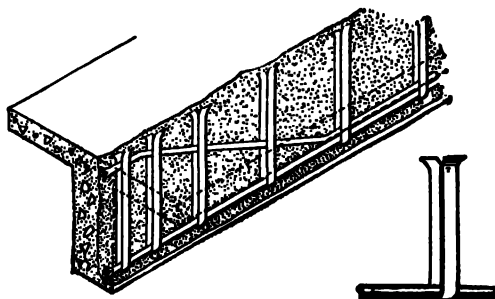


Fig. 54.—Hennebique systen

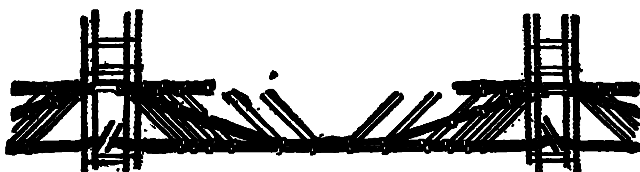


Fig. 55.—Pin-connected system.



Fig. 56.—Luten truss.

Pin-connected System.—Reinforcement in the pin-connected system consists of bars made into a truss and ready for placing in the forms (see Fig. 55).

Luten Truss.—The Luten truss is shown in Fig. 56. The bars are rigidly locked together to form the truss by a clamp, with a wedge that is self-locking when driven home. The truss

is especially adapted to highway culverts and bridges and is put out by the National Concrete Co.

Xpantruss System.—The truss by this name is shown in Fig. 57 and is applicable chiefly to beams, girders, and heavy slabs. This system is patented by the Consolidated Expanded Metal Co.

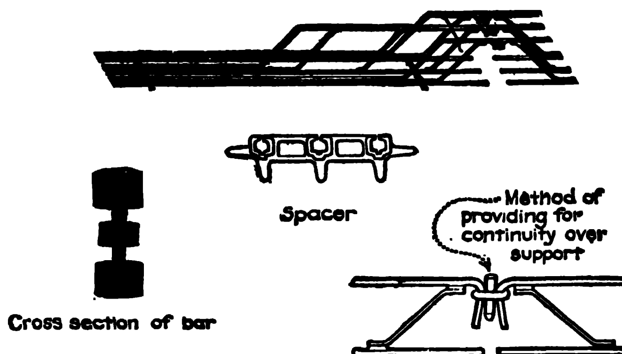


Fig. 57.—Xpantruss system.

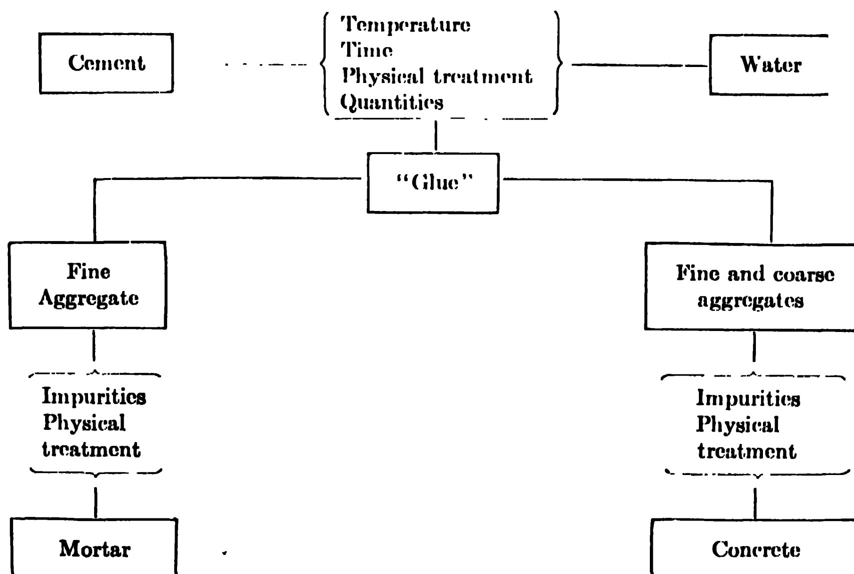
CEMENT MORTAR AND PLAIN CONCRETE

By H. E. Pulver

Concrete, as used in construction, is a mixture of cement, water, and fine and coarse aggregates. The cement is usually a standard Portland cement; the fine aggregate, a sand; and the coarse aggregate, a crushed stone or gravel.

Cement mortar is a mixture of cement, water, and a fine aggregate (usually sand).

136. Formative Processes in Concrete.—Perhaps the easiest way to consider a concrete mixture (or cement mortar) is to think of the cement and water as forming a "glue" or paste, which, upon hardening, acts as a binder cementing the particles of the aggregate into a permanent mass. Diagrammatically, the formation of the concrete or mortar is as follows:



If a comparatively large amount of water is mixed with the cement to form a "glue," or paste, the glue will be thin and watery, and, though it will "glue" together a comparatively large number of particles of aggregate, the strength of the glue and the strength of the resulting concrete will be low. Likewise, if a comparatively small amount of water is used, the glue will be thicker and stronger but will not bind or glue together such a large number of particles of aggregate.

The hardening of a Portland cement mortar or concrete is due to a chemical reaction between the cement and the water. The rate and the amount of hardening depends upon several things such as the proportions of cement and water, temperature, quality of cement, presence of impurities, thoroughness of mixing, care in placing, and care and protection when curing.

137. Qualities Desired in Concrete.—The three fundamental qualities of good concrete are strength, durability, and economy. The concrete must be strong enough to carry the load, durable enough to last for years, and economical especially in regard to cost.

Other desirable qualities are water tightness, resistance to wear, bond strength with steel, workability, and uniformity. Fortunately, the qualities of water tightness, wear resistance, and bond strength with steel parallel the compressive strength of the concrete.

To secure good concrete it is necessary that good materials be used. These materials must be correctly proportioned, thoroughly mixed, carefully transported and placed, and adequately cured. Failure to meet any one of these requirements will probably result in poor concrete.

138. Strength.—The strength of a plastic and workable concrete mixture depends primarily upon the water-cement ratio—that is, the ratio of the water to the cement, commonly spoken of as the number of gallons of water per sack of cement. The Portland Cement Association states the water-cement ratio strength law as follows:

For given materials and conditions of manipulation, the strength of concrete is determined solely by the ratio of the volume of the mixing water to the volume of the cement as long as the mixture is plastic and workable.

The curves in Fig. 58 show the relation between the 28-day unit compressive strength of concrete and the water-cement ratio. Different materials will give slightly different curves from the ones shown in Fig. 58, but concrete mixtures of good materials properly proportioned, mixed, placed, and cured will give curves nearly parallel to curve *A* and usually a little above. It is desirable to have tests made for each job so that a job curve can be drawn giving the relation between the water-cement ratio and compressive strength for the materials to be used.

Formulas which will give practically the same results as the curves in Fig. 58 for 28-day unit compressive strengths are

$$S = \frac{27{,}700}{gs} - 1700 \text{ for good working conditions}$$

or

$$gs = \frac{27{,}700}{S + 1700}$$

and

$$S = \frac{24{,}400}{gs} - 1700 \text{ for poor working conditions}$$

or

$$gs = \frac{24{,}400}{S + 1700}$$

where S = the 28-day unit compressive strength of the concrete.
gs = gallons of water per sack of cement.

The strengths of concrete in tension, cross-bending, shear, and bond with steel are governed by the water-cement-ratio law, and the curves obtained are usually roughly parallel to the compressive strength curves. The approximate ultimate strength of concrete in tension is about 10% of the ultimate compressive strength, in shear about 50%, and in bond about 10%.

The strength of good concrete increases with age as long as moisture is present and the temperature is favorable. The increase in strength is very rapid in the early age and continues

more slowly for an indefinite period. The curves shown in Fig. 59 illustrate the increase in the compressive strength of concrete with age.

The following formula was developed by Slater from experimental data to show the approximate relation between the 7- and the 28-day unit compressive strengths of concrete:

$$S_{28} = S_7 + 30\sqrt{S_7}$$

where S_7 and S_{28} are the 7- and 28-day unit compressive strengths respectively.

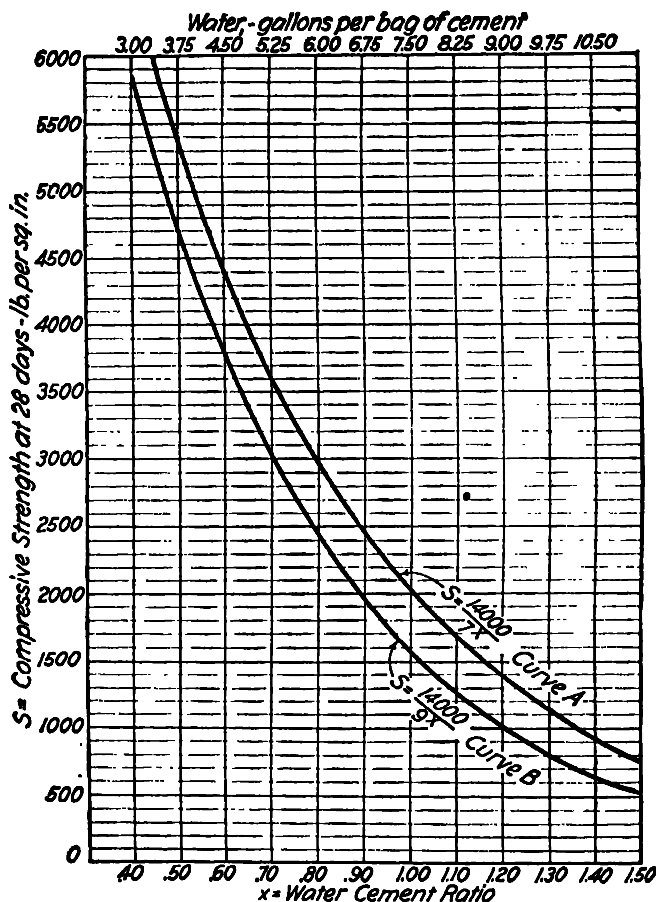


FIG. 58.—Relation between the compressive strength of concrete and the water-cement ratio.

The effect of a variation in the time of mixing on the 28-day unit compressive strength of concrete is shown graphically in Fig. 60. These curves show that there is a fairly rapid increase in strength for different periods in mixing up to about 2 min., after which the increase is less rapid. Mixing as long as 25 to 30 min. does no harm.

The effect of curing conditions on concrete cannot be overemphasized. The concrete should be kept damp if possible for a week to 10 days in ordinary construction, so that enough water will be present to permit the slow process of chemical hardening (hydration). If the concrete is allowed to dry out too soon, part of its potential strength will be lost. Damp curing, particularly in the early stages of hardening, is essential and aids in securing a hard, dense surface and in preventing checking and dusting.

The effect of temperature during the curing period is shown by the curves in Fig. 61. Note that concrete allowed to harden at a temperature near freezing for 28 days will be only about 60% as strong as a like mixture hardened at 70 deg. F. The curves in Fig. 61 show that it is advisable to keep the temperature above 50 deg. F. on construction work, especially during the early stages of curing.

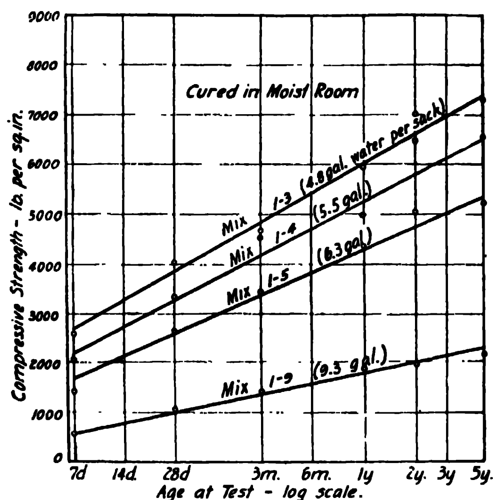


Fig. 59.—Increase in compressive strength of concrete with age.

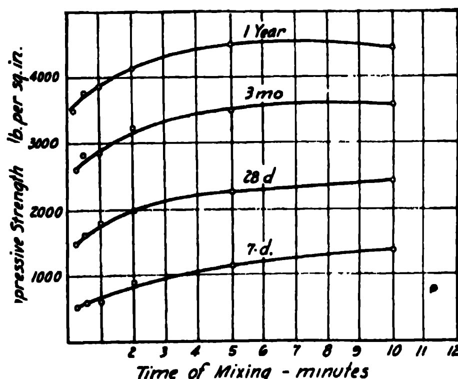


Fig. 60.—Typical relation between time of mixing and compressive strength of concrete.

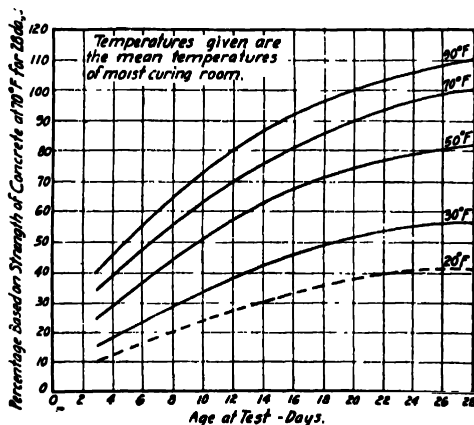


Fig. 61.—Effect of temperature during curing period on the compressive strength of concrete. Data taken from *Bulletin* No. 81, Engineering Experiment Station, University of Illinois.

139. Durability.—The durability of a concrete mixture depends primarily upon its resistance to weathering conditions. In general, a concrete that is water resistant will prove to be durable if the concrete is made of proper materials. Tests have shown that a concrete mixture having a water-cement ratio of about 6.75 gal. per sack of cement or less is practically water tight and durable for ordinary plastic, workable mixtures. The water-cement ratio has considerable influence upon the durability. It is understood that the cement, water, and aggregates are of good quality and that the mixture is correctly proportioned, mixed, placed, and cured.

The Portland Cement Association recommends the following water-cement ratios for different types of structures or degrees of exposures:

CLASSES OF CONCRETE FOR DIFFERENT DEGREES OF EXPOSURE

Class of concrete (expected strength at 28 days, pounds per square inch)	Maximum quantity* mixing water U. S. gallons per sack of cement (94 lb.)	Type of structure or degree of exposure
3000	6	Roadways, piles, pressure pipe, and tanks. Thin structural members in severe exposure. Walls, dams, piers, etc., where exposed to severe action of water and frost
2500	$6\frac{3}{4}$	Sewers, bridges, walls, dams, piers, etc , for all weather conditions and moderate action of water and frost
2000	$7\frac{1}{2}$	Ordinary enclosed reinforced concrete buildings. Bridges and retaining walls of heavy sections in moderate exposure
1500	$8\frac{1}{4}$	Mass concrete, basement walls, etc., protected from water or severe weather conditions

*Free water or moisture carried by the aggregates must be included as part of mixing water.

140. Economy.—The economy of a concrete mixture, other things being equal, depends primarily upon the grading of the aggregate, so that as large an amount of the aggregate can be used as practicable without affecting the strength or workability of the concrete. As aggregates cost less than cement, the larger the proportion of aggregate the less the cost of the concrete.

For a concrete mixture to be workable, the fine aggregate should not be more in volume than the coarse or less in volume than half of the coarse aggregate. Usually, if the fine aggregate is more in volume than the coarse aggregate, the mixture will be "oversanded" and uneconomical. Also, if the fine aggregate is less in volume than half of the coarse aggregate, the mixture is generally harsh and not workable.

For good economy, as large a size of coarse aggregate should be used as practicable, and as small an amount of fine aggregate mixed with the coarse aggregate as will be satisfactory to give a mix of the desired workability.

141. Water Tightness.—Investigations and tests have shown that a concrete mix having a water-cement ratio of 6.75 gal. per sack of cement or less will usually be water tight for all ordinary purposes. If the concrete is to be subjected to severe action of water and frost, the water should be reduced to 6 or even 5.5 gal. per sack of cement.

The grading of the aggregate also has some influence on the water tightness of the concrete mix. There should be a sufficient amount of fine particles, as it has been found that a slight excess of fine particles tends to make the mix more water tight. If the aggregate is deficient in fine material, some fine material should be added in the form of cement, hydrated lime, clay, fine earth, puzzolan cement, feldspar, or other waterproofing materials such as are on the market.

In addition to the proper proportioning of the mixture, the concrete may be made more waterproof or water repellant by the addition of integral compounds to the mixing water, such as an alum soap solution, lime chloride, wax, mineral-oil residuum, or other manufactured compounds.

The surface of the concrete may be waterproofed by the addition of waterproof coatings such as alum, lye, and cement washes; alum and soap mixtures; cement grout, with or without a water repellant; paraffines, waxes, or other mineral bases applied in a melted condition or cold in a solution; various varnishes or paints; coatings of tar, asphalt, or oil; asphalt mastic or by adding layers of felt and asphalt or tar compounds.

142. Workability.—If a concrete mixture is not plastic and workable, the mixture is difficult to handle and place. Also, if the mixture is very harsh, the water-cement-ratio law will probably not apply in regard to strength and water tightness.

The relative workability or consistency of a mixture may be measured by the slump test, provided that the mixture is not harsh. While the slump test is not an absolute measure of workability, it is about the best test yet discovered. Under conditions of uniform operations, the slump test will indicate changes in the character of the materials, in the water content, or in the proportions.

The Portland Cement Association recommends the following slumps for concrete:

RECOMMENDED SLUMPS FOR CONCRETE

Type of structure	Slump, inches	
	Minimum	Maximum
Massive sections, pavements and floors laid on the ground	1	4
Heavy walls, slabs, beams	3	7
Thin walls, columns, etc.	4	8

The correct amount of mixed aggregate to use for any one batch can be found by cut-and-try methods, using the slump test.

When the water-cement ratio is specified, the workability of a batch is governed by the amount of aggregate added and by the grading or the relative proportions of the fine and coarse aggregates. The mixture must not be too harsh for proper placing or contain too much fine aggregate for proper density.

The best proportions of fine and coarse aggregate to use may be found by mixing trial batches to find which will give the greatest yield for a given slump. In general the ratio of coarse to fine aggregate will be within the limits given by the following table:

RECOMMENDED PROPORTIONS OF AGGREGATES

Maximum size of coarse aggregate, inches	Ratio of coarse to fine on basis of dry-compact volumes	
	Minimum	Maximum
3/8	0.40	0.80
3/4	0.60	1.50
1 and over	1.00	2.00

143. Uniformity.—Uniformity in concrete mixes means uniformity in materials (cement, water, fine and coarse aggregates), in measuring materials, in mixing, in transporting, in placing, and in curing. Variations in the amounts or qualities of the materials in the batches as well as in the mechanical processes of mixing, handling, and curing of the mixture will produce variations in the strength and other properties of the resultant concrete. Careful attention to uniformity aids in securing concrete which will be economical and as designed.

144. Control of Concrete in Construction.—Satisfactory control of concrete in construction work depends upon the following factors:

Materials.
Proportioning.
Measuring and mixing.
Transporting.
Placing.
Curing.
Follow-up tests.

Materials.—The materials for concrete work should be carefully chosen in regard to quality, quantity, uniformity of supply, and availability.

The cement should be a Portland cement conforming to the Standard Specifications and Tests for Portland Cement of the American Society for Testing Materials.

The water should be suitable for drinking purposes, unless it is shown by test or experience that other waters are satisfactory.

The aggregates should satisfy requirements in regard to kind of materials, grading, cleanliness, presence of impurities, uniformity of supply, location of source of supply, quantities available, and capacity for delivering uniform and adequate quantities at the job. Tests should be made for grading, silt, and organic matter. In general, satisfactory aggregates will conform to the specifications of the American Society for Testing Materials.

The cement on the job should be stored in a weathertight building. The aggregates may be stored in bins or stock piles where they will be protected from impurities such as dirt, organic matter, etc.

Proportioning.—The proportioning of the concrete mixtures must be carefully done to give batches of desired strength and workability for the particular job in question.

General rules for the proportioning of concrete mixes are as follows:

1. Use Portland cement, water, and aggregates of good quality.

2. Base the strength on the water-cement ratio. Make due allowance for the water in the aggregates.

3. Base the required workability of the mix on the particular job in question, using a mix as dry as practicable. The slump test may be used as a measure of workability.

4. Add mixed aggregate to the cement and water to give the desired workability.

5. For economy, grade and combine the fine and coarse aggregates so that the greatest proportion of mixed aggregate can be used and yet have a mix of the desired workability.

Measuring and Mixing.—The choice of equipment for measuring and mixing concrete materials will depend upon the size and kind of the particular job and upon the requirements as to control and uniformity. No method of measurement yet discovered is "fool proof," and care must be exercised at all times, regardless of the method selected.

Portland cement is usually measured by the sack, 1 sack (94 lb.) to be considered as 1 cu. ft.

Aggregates may be satisfactorily measured by weight or by volume. Batcher plants are coming into common use and are satisfactory. The choice of measuring by weight, by volume, or by volume using the inundation method for sand and water will depend upon the equipment available and upon the opinion of the contractor or engineer. If an inundator is not used, allowance must be made for the bulking effect of moisture in the sand when measuring by volume.

Water may be measured by weight or by volume. Perhaps the more common way is by volume. Accurate control of the mixing water is of extreme importance, especially when the mixture is designed according to the water-cement-ratio law. Corrections must be made for the moisture content in the aggregates. Moisture tests should be frequent when the stock piles of aggregates have been subjected to rains or to rapid drying out. Many concrete mixers are provided with water-measuring devices which can be set and locked and which will not permit the passage of water into the mixer except at the proper times. The water measurement should be such that the water content in any one batch will not vary more than ¼ gal. (about 2 lb.) per sack of cement.

Good batch mixers of small, medium, and large sizes are available, so that the correct size of mixer can be selected for the job in question. In a batch mixer the mixing is done by the rotation of the drum or by moving paddles or blades, the material being raised, cut, and turned. The mixers may be charged by a hopper or a lifting skip and discharged by a spout or by tilting the drum. The water is usually added from a tank, preferably an automatic one, commonly placed over the mixer. The speed of the drum should be about 200 ft. per min. If the rotation is too fast, the materials will tend to be held next to the rim, while if the rotation is too slow, more time will be required for thorough mixing. The time of mixing should not be less than 1 min., and more time is advisable when mixing concrete that is to have a high early strength or

that is to be water tight. The mixer should not be overloaded. It should be cleaned at the end of the work and at the end of each day's run.

Transporting Concrete.—The transportation system should be so designed and operated that the concrete will be carried from the mixer to the forms before initial set has occurred. No part of the concrete should be lost, and there should be no segregation of materials. Also, the work of transporting the concrete should be efficiently, rapidly, and economically done. The choice of a transportation system depends upon the particular job and upon the plant available. Sometimes the transportation plant used affects the design of the mix, chutes often requiring a mix with a larger slump than when carts and buckets are used.

Placing Concrete.—Careful placing of the concrete is of great importance and requires careful supervision to prevent segregation, to see that the concrete flows readily in the corners and angles of the forms and around the reinforcement, and to see that it is placed in even layers of the desired thickness.

Frequently, when the concrete is placed in deep layers, water will collect on the top of the concrete due to the increased pressure in the lower portions. The extra water should be removed, as this excess water is just as objectionable as excess mixing water. Sometimes it may be advisable slightly to reduce the water content of the following batches.

Excess water may cause a layer of laitance on the top of the concrete if the work is halted for a time (say, overnight or even a few hours). This laitance and a small layer of the concrete adjacent should be removed before new concrete is placed.

The concrete, when deposited, should have a temperature between 50 and 120 deg. F.

Curing.—After the concrete is placed, it must be allowed to "cure" or harden. This hardening is a rather slow process, and the fresh concrete should be protected for a week or 10 days from shocks, excessive vibration, loads, extreme heat, cold and freezing temperatures, too rapid drying out, and contact with impurities which may retard, stop, or destroy the chemical action.

The Portland Cement Association recommends that the fresh concrete be allowed to harden in the presence of moisture for the first 10 days.

Forms for concrete should not be removed until the concrete has hardened sufficiently to carry its own weight and the loads which may be placed upon it. The following table gives the approximate lengths of time that forms should be left in place.

TIME REQUIRED BEFORE REMOVING FORMS

Member	Temperature		
	Above 60 deg. F.	45 to 60 deg. F.	Less than 45 deg. F.
	Required time, days		
Compression members such as columns and walls	4 to 6	not less than 10	Not until tests have been made that show that the concrete has thoroughly hardened
Side forms of frames and girders	5 to 7	not less than 10	
Bottom forms of slabs of short span	6 to 10	not less than 14	
Bottom forms of beams and girders	7 to 14	not less than 14	

It is customary to leave some shores in place under the bottoms of the beams, girders, and slabs for a week or two after the side and bottom forms have been removed.

Follow-up Tests.—Whenever practicable, follow-up tests should be made to check up on the control of concrete in the field. These tests should include some tests of each daily operation and also some specimens during an occasional day's operations to give the daily variation.

After the work has been well organized and the quality of the concrete well established, the number of tests and specimens may be reduced.

The test cylinders (usually, 6 in. in diameter and 12 in. high) should be made, stored, and tested in accordance with the requirements of the American Society for Testing Materials for "Standard Methods of Making and Storing Specimens of Concrete in the Field" and for "Standard Methods of Making Compression Tests of Concrete."

The moisture content of the test cylinder has a decided influence on the compressive strength. A saturated specimen will show a strength from 20 to 30% less than when tested dry. The standard procedure calls for the cylinders to be tested just as they are taken from the moist room or wet sand.

145. Miscellaneous Properties of Concrete. *Absorption.*—The absorption of water by plain concrete may be comparatively small or great, depending upon the density of the concrete, richness of the mix, kind of aggregates used, proportioning, thoroughness of mixing, and care used in placing and curing. In general, the factors that tend to make a concrete water tight will also tend to make it non-absorptive.

Expansion and Contraction.—Concrete may shrink a little when hardening in air and may keep the same volume or expand a little when hardening in water. Tests have shown that the shrinkage of concrete mixtures cured in air varies directly with the richness of the mix and inversely with the size of the aggregate, the greater effect being caused by the aggregate. Rich mixes will shrink more than lean ones. The effect of the size of the aggregate is approximately as follows:

Mixtures with 1½-in. aggregate will shrink about 0.6 in. per 100 ft.

Mixtures with ¼-in. aggregate will shrink about 1.2 in. per 100 ft.

Neat cement paste will shrink about 2.4 in. per 100 ft.

The coefficient of expansion for concrete is about 0.000006 per deg. F., and this coefficient varies but little for the different mixes and aggregates commonly used.

Abrasive Resistance.—The abrasive resistance of the concrete depends primarily upon the abrasive resistance of the mortar, which, in turn, depends upon the ability of the cement to hold the sand grains together and also upon the abrasive resistance of the sand grains themselves. When the surface of the concrete is worn away so that the coarse aggregate is exposed, the abrasive resistance then depends partly upon the abrasive resistance of the coarse aggregate.

Weight per Cubic Foot.—The weight of good sand and crushed stone or gravel concrete varies from about 135 to 160 lb. per cu. ft., with an average value of about 145 lb. per cu. ft. for plain concrete. Concrete made from cinders, slag, and other light-weight aggregates will have a lesser unit weight than the values given.

146. Effects of Various Substances on Concrete.—The effects of various substances upon concrete may be divided into two classes: (1) the effect of various substances mixed with the concrete and (2) the effect of various elements on the hardened concrete.

Effect of Mixing Various Substances in Concrete

Air.—Air is commonly present in the form of air voids. Much of the air can be removed by thoroughly compacting the concrete in the forms.

Clay and Silt.—A little finely divided clay or silt tends to make the concrete (especially the leaner mixtures) more water-tight and workable. An excess of clay or silt (say, more than 10%) may cause a decided loss of strength.

Loam and Dirt.—These materials, if organic matter is not present, have about the same effect as clay and silt. Loam and dirt should be excluded from concrete mixes, however, because some organic matter is usually present.

Lime.—Unhydrated lime (quicklime) should never be added to a concrete mix, as the expansion of the lime when hydrating will probably cause expansion and disintegration of the concrete. Thoroughly hydrated lime has about the same effect as clay and is preferable to clay.

Organic Matter.—All organic matter should be excluded from concrete mixtures, because as small an amount as ⅒ to 1% may be injurious.

Mica.—A small amount of mica in a concrete mixture will cause a decided loss of strength.

Sugar.—A small percentage of sugar in a concrete mixture greatly reduces the strength and durability of the concrete.

Sea Water.—It is not thought advisable to use sea water as mixing water for concrete, though some tests have not shown a very great loss in strength.

Salt Water.—Mixing waters, containing more than a few per cent of common salt in solution, may cause a decided loss of strength.

Acid and Alkali Waters.—Mixing waters containing much acid or alkali frequently reduce the strength and durability of the concrete.

Effect of Various Substances on Hardened Concrete

Frost.—In general, freezing has but little effect on good hardened concrete made from mixtures having a water-cement ratio of 6.75 gal. per sack of cement or less. Freezing and thawing of wet and comparatively porous concrete frequently causes disintegration and spalling of the exposed surfaces.

Fire.—Good concrete is little affected by fire for temperatures under 1200 deg. F. (as hot as an ordinary fire). Fire causes a change in a thin layer on the outer surface of the concrete, and this layer then serves as a protection for the remainder of the concrete. Aggregate, which will burn or disintegrate at temperatures less than 1700 deg. F., should not be used in concrete which may be exposed to fire. In some instances, expansion and contraction, due to the application of fire and streams of water, may cause trouble.

Sea Water.—Sea water appears to have but little effect on good dense concrete made from mixtures having a water-cement ratio of about 6 gal. per sack of cement or less. Poor concrete often disintegrates when exposed to the action of sea water.

Alkali.—Alkali water has about the same effect as sea water.

Acids.—In general, good, dense, thoroughly hardened concrete is effected only by such acids as would seriously injure other materials.

Oils, Greases, and Miscellaneous Liquids.—For the effect of oils and miscellaneous liquids on hardened concrete and the method of protective treatment where required, the reader is referred to Appendix 17 of the 1924 *Report* of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete.

147. Quantities Required per Cubic Yard.—The common units of measurement for concrete mixes are the cubic foot and the cubic yard. One sack of cement (94 lb.) is considered as 1 cu. ft. One barrel of cement contains 4 sacks.

The following rule may be used in computing the quantities of materials required for 1 cu. yd. of concrete. The proportion of cement, c, is taken as unity.

Sacks of cement per cubic yard of concrete

$$= C = \frac{42}{c + s + g}$$

Cubic yards of fine aggregate per cubic yard of concrete

$$= S = \frac{1.55 \times c}{c + s + g} = \frac{C \times s}{27}$$

Cubic yards of coarse aggregate per cubic yard of concrete

$$= G = n\frac{1.55 \times g}{c + s + g} = \frac{C \times g}{27}$$

When c, s, and g are the proportions by volume of cement, fine aggregate, and coarse aggregate respectively.

If the proportions by volume are for cement and mixed aggregate, the volume of the mixed aggregate may be taken equal to the volume of the concrete, and the volume of the cement based on the volume of the mixed aggregate. For example, a 1:5 mix by volume of cement to mixed aggregate would require, for 1 cu. yd. of concrete, 1 cu. yd. of mixed aggregate and $^{27}/_{5}$ or 5.4 sacks of cement.

The rule which follows may be used when computing weights of materials per cubic yard of concrete (assuming a cubic yard of concrete to weigh 4000 lb.). The proportion of cement,

c', is taken as unity, and c', s', and g' are the proportions by weight of cement, fine aggregate, and coarse aggregate respectively.

Sacks of cement per cubic yard of concrete

$$= C' = \frac{42.5}{c' + s' + g'}$$

Tons of fine aggregate per cubic yard of concrete

$$= S' = \frac{2s'}{c' + s' + g} = \frac{C' \times s'}{21.25}$$

Tons of coarse aggregate per cubic yard of concrete

$$= G' = \frac{2g'}{c' + s' + g'} = \frac{C' \times g'}{21.25}$$

To reduce sacks of cement to pounds, multiply by 94

The water may be measured in cubic feet, gallons, or lb. One cubic foot of water may be considered as containing 7.5 U. S. gal. and weighing 62 5 lbs. One U. S. gallon contains 231 cu. in. and may be considered as weighing 8.35 lb. Water contained in the aggregates must be considered when measuring mixing water for any batch.

REINFORCED CONCRETE

By Nathan C. Johnson

As pointed out in the preceding chapter, concrete has low strength in tension, though high strength in compression. To overcome the weakness of plain concrete in tension, steel is added. This addition is usually in the form of bars, embedded in the concrete mass while plastic and in quantities dependent upon the nature and magnitude of the stress to be sustained.

148. Steel as a Component Material.—Fortunately for the success of the combination, steel possesses substantially the same coefficient of expansion as does concrete. This means that one relationship is established between steel and its surrounding concrete, variations in temperature will not alone bring about its disturbance, but that the two will co-act. It is possible, however, that stress might bring about a change; and in order to minimize these possibilities, the bars are usually of "deformed," or irregular section, in order to assist the natural bond formed with the encasing materials, the steel in all cases acting as an aggregate of special forms and qualities, held in place and made of value by the same "glue" that acts on other aggregates.

149. Concrete as Fire Protection for Steel.—A further advantage is obtained with this combination in that concrete, which has a low heat conductivity combined with rigidity, acts as a "fireproofing" for the embedded steel, enabling it to continue unimpaired its stress-resisting functions under conditions, as in a fire, where steel not thus protected would speedily become soft and useless.

150. Concrete as a Rust Protection for Steel.—Where moisture and oxygen have access to steel, rusting is unavoidable. Steel encased in a dense concrete, however, rusts little if any, due partly to the chemical effect of lime hydrate derived from the cement, but more particularly to the prevention by the surrounding concrete of water having access to the steel. But where concrete is porous, rusting proceeds. And rusting results further in expansive pressure, so that not only is the steel destroyed to greater or less extent by the rusting, but the protective casing is also split off by the same agency.

151. Concrete of Proper Quality the Prime Requisite.—It is evident from the above that in the concrete-steel combination, proper quality of concrete is of first importance. Reinforcement plays its chief part by functioning in tension. It cannot function alone in compression, nor is it able to withstand, without proper bedment in concrete of good quality, the destructive agencies above noted. Reinforcement should be given its proper dues, but the use of reinforcement confers no license to violate the rules of the proper making of concrete, nor by its use is a

new and magical substance created. The first step in the successful use of reinforced concrete is to cover the reinforcement with the best concrete that can be produced, which involves all the factors set forth as influencing concrete when made without steel.

152. Weight of Reinforced Concrete.—Reinforcing steel adds from 3 to 5 lb. per cu. ft. to the weight of plain concrete, when used in usual quantities. Reinforced concrete is assumed in design to weigh 150 lb. per cu. ft., but this again depends upon the density of the concrete surrounding the steel and upon the aggregate employed in it. Special light-weight aggregate employed by the U. S. Shipping Board in constructing reinforced concrete ships is said to have a weight as low as 100 lb. per cu. ft.

153. Unit Stress Values for Reinforced Concrete.—See the Joint Committee's *Report*, Appendix *J*.

CONCRETE BUILDING STONE

By Harvey Whipple

A changing economic situation has in recent years been greatly to the advantage of concrete masonry unit production. Concrete has had widespread acceptance, not only in the standard dimension units of brick, light-weight structural tile, and the older and heavier block, but also as made to detail and dimension to meet exacting specifications for highly architectural requirements.

Concrete building units were first accepted as a substitute for other more thoroughly established materials. They are now generally used in both large and small centers on an equal or preferred basis.

Along with economic conditions which have made possible the use of concrete building units there have been changes within the concrete masonry unit industry: Sizes, methods, machines and quality have been standardized; capital and able management have replaced small producing plants with large manufacturing establishments; the multiplied economies of quantity production have fostered refinements of control and emphasized the importance of scientific knowledge, so that the gross savings, which in small-scale production were insignificant, become a substantial and often a sufficient profit. Thus, the industry honestly earns its way, and the economic tide toward concrete has been swelled by economic advantages which remained undiscovered until production "by the million" became a fact. The development of light-weight aggregates—cinders, burned clay and slag—have contributed much to the usefulness and adaptability of concrete masonry units.

154. Grades of Concrete Building Stone.—Superior grades of concrete stone building units are made to measure from architects' details and are surface dressed to reveal texture and color. They rival natural stone in every way and, in many instances, are far less likely to suffer discoloration and disintegration from exposure to the atmosphere and to frost. There is a great difference between such concrete stone building units and the ordinary concrete building block, made in machines or multiple molds in standard unit sizes. Again while there is a great difference among products of standard machines or multiple molds, depending upon the manufacturer's choice of field, there is a steady improvement in standards in each class of materials. Each of the various grades and kinds of concrete stone are to be had in some localities, while in others, one grade or kind dominates. Each one of them has its uses.

155. Uses of the Cheaper Grades of Concrete Stone.—There has been increasingly general acceptance in municipal building codes of the standards of quality set up by the American Concrete Institute for concrete brick, block, and structural tile. Except in rural communities, there is a decreasing use of the old rock-face block, which, as an outcome of a desire to imitate other material, did much at one time to injure the standing of concrete building units generally.

Production of standard-dimension, machine-made block, brick, and tile is chiefly in plain, serviceable units, either for facing with stucco or other material or for purely utilitarian walls where a special covering is dispensed with.

Units with surfaces of special mixtures to meet more exacting requirements as to appearance without veneer are made and used in large quantities but are a small percentage of total production.

High-quality dimension stone has had very intelligent development in some centers and has steadily gained favor with architects for important work.

There is a wide range of kind and quality in the dimension stone market, varying with the developments in technique by individual manufacturers and with proximity to the sources of competitive materials of various degrees of structural and architectural merit. In general, it may be recorded that concrete trim stone may be and is made as good as the market demands — some of it dense and non-staining and testing higher than 5000 lb. per sq in., while other products are porous, friable, and test a scant 1000 lb.

Variations in quality and lack of conformity to any fixed standard are expected to yield to efforts of some of the more progressive manufacturers through the American Concrete Institute which has adopted (Feb. 1929) "Tentative Specifications for Cast Stone" requiring 5000 lb. per sq. in. compressive strength at 28 days, testing 2-in. cubes or cylinders and an absorption of not less than 3% nor more than 7% of water by dry weight of the specimen in accordance with a specified test procedure.

156. Methods of Manufacture.

156a. Dry-tamp Method.—"Dry-tamped" products have been by far the most common. In earlier days, tamping was often inadequate, mixtures too dry, and materials too fine to produce units which would compete favorably even with common brick. With the advancement of the industry has come better machinery and a better understanding of the means which ensure products of a high-standard quality. It has been fortunate that economy is achieved by a scientific grading and proportioning which give a better concrete with less cement. Coarser, better-graded aggregate cuts down the cement proportion. More water in the mix, better tamping, and better curing conditions have worked in the same direction. The whole course of progress in the refinement of production methods has favored the larger manufacturing enterprises, where substantial profits have been made of what was wasted in many small plants where quality control was not practiced. Thus, the so-called dry-tamped concrete unit has come into better favor. While in reinforced concrete and in mass concrete construction generally, Abrams' water-cement-ratio theory has been taking water out of the batch and giving better concrete for less investment in cement, the dry-tamped block manufacturers have had to study the dry side of the water-cement-ratio curve. Under a necessity to use a mix stiff enough to stand up immediately after molding, it has been discovered that coarser, wetter mixtures could be used successfully. Hand tamping is less and less used; machine tamping has been improved.

"Stripper" Block.—If block or tile are to be produced solely for structural purposes, probably the simplest molding operations are attained in that type of machine which produces the block upright in the mold and in the machine introducing and removing the cores forming the hollow space in upward and downward motions. Thus the faces of the block are always perpendicular to the bed of the machine, and the block is "stripped" out of the mold with a trowelling action on its sides. Such equipment permits the use of concrete of more nearly ideal consistency than tamp equipment of other types.

Faced Block.—When block are to be produced faced with a special facing mixture, used only in a thin layer next to the exposed face or faces, the machine chosen will be of the face-up or face-down type. It will readily be seen that where a layer of special material is to be backed up with a different body mixture of concrete, the molding operation will be much more simple if the facing is placed in a layer on the bottom or else on the top; in either case on a horizontal surface. Where more than one side of a block is to be faced it is, of course, a comparatively simple matter, but less rapid, to put the facing at the side.

Operation of Cores.—The manufacture of hollow units, in which from 25 to 50 % or more of the horizontal area of a block is air space, involves a variety of machine features in the creation of air spaces.

In most machines the cores are introduced into the mold box by a movement of a lever after a part of the mixed concrete has been deposited and compacted. The remaining space between, around and above the cores is filled and compacted and the excess material struck off, either by a movement of a hand straight-edge or by a device forming a part of the machine. The "feed" of the concrete has been a special study recently by an American Concrete Institute committee.

Some machines provide for the withdrawal of these cores horizontally, and some equipment is so designed that after the box is filled the mold box is turned over; the core is then removed by a downward motion. The chief value of equipment which provides that the cores shall be withdrawn downward is in the fact that the walls and the cross-webs of the block stand vertically on the pallet before the support of the cores is removed. This reduces the tendency of the walls of the block to sag into the hollow space or spaces. Such equipment usually permits the use of a slightly wetter mixture of concrete than can be used in a machine with similar core areas where the core is withdrawn horizontally, inasmuch as, with given materials, the tendency to sag increases (beyond a certain degree of minimum wetness) with the proportion of water in the mixture.

The cores, as the block is molded, are in a horizontal position and the block in its vertical dimension is thus also in a horizontal position.

156*b*. Pressure Method.—The application of pressure in compacting concrete is accomplished in both hand and power driven equipment. Pressure machines are made for the exertion of mechanical pressure by hand or power, and other machines are hydraulic in their application of pressure.

In their operation it is generally possible to use a slightly wetter mixture than can be successfully manipulated under most machines which rely upon tamping in securing density, yet in this, as in tamp machines, much depends upon how the product is released from the mold. Too wet a mixture in a dry-tamp machine will be displaced by tampers, rather than compacted. In pressure machines the compacting force is exerted evenly over the entire area of the mold box, and displacement is impossible.

156*c*. Wet-cast Method.—"Wet-cast" products are made by two distinctly different methods and with entirely different results.

To meet the criticism of concrete block made by the "dry-tamp" method that they were made so dry that they were thirsty in every rain that followed (which was undoubtedly true of many products), multiple steel molds came into use. These gang molds are ordinarily made of sheet and pressed steel. The molds are usually mounted upon trucks so they may be moved to the mixer, filled, and rolled away to harden until the following day when the mold sections are taken down, oiled, and reassembled. Such multiple molds have cores formed also of pressed steel and these lie in the molds in a horizontal position. To fill the molds rapidly around these cores the block manufacturer frequently goes as far to the extreme of wetness as the dry-tamp manufacturer goes in the other direction.

The other wet mix method of manufacture involves the use of sand molds, not unlike those used in iron foundries. The sand mold method involves the making of special patterns, under and around which the sand is tamped on the casting floor. Then the patterns are removed in one piece, if it is so-called "straight" work, or in several pieces as previously provided to meet the requirements of the special unit. The sand mold remaining is filled with a wet but smoothly mixed concrete and most of the excess water is taken up by the mold itself, with a result much different from that obtained when an equally wet mix is cast in a tight mold of wood, steel, or plaster. The disadvantages of wet concrete are overcome by means which, before hardening, bleeds the mix of its excess of water.

157. Consistency.—While the study of concrete has led the industry through dry mixes which must be tamped and wet mixes which must be puddled, it is now well established that Portland cement requires a definite quantity of water to effect its hydration, and that the use of water in that quantity, other factors remaining equal, gives a product of maximum strength and density. It has been shown by plotting the results of using various percentages of water that the quality of the concrete falls off very rapidly on both sides of the peak of the curve.

The best tamped products will show web-like water markings when released from the mold in which it has been compacted. The ideal consistency would cause the concrete to sag slightly when released from the mold. The use of such a mix is impracticable with equipment which requires the immediate release of the product from the mold. The nearest approach to the ideal mix is probably attained in the use of the "stripper" machines, and in the use of machines where the concrete is shaped under pressure with no horizontal webs to break down over the arches. A very few manufacturers cast trim stone in special wood molds using a mixture of practically ideal consistency and with no attempt to remove the mold from the product until several hours after placing. The ordinary dry-tamp and ordinary wet-cast concrete generally used in block and stone manufacture are both wrong—they depart from the ideal in opposite directions, but for a choice between them it is probably "six of one and half a

dozen of the other." The tamped product has been improved when the manufacturer has used a maximum of water; the wet-cast product has been improved by an insistence upon a minimum of water.

Careful workmanship will admit of using more water in tamped concrete, even with equipment least adapted by mechanical limitations to the work. The deficiency of water will be less disastrous when the finished product is hurried to curing rooms—to atmospheric conditions which prevent the concrete, already deficient in water, from losing by evaporation any of the moisture it contains, so that all that moisture may be utilized in hydrating the cement.

The tamped product will be improved by the perfection of equipment so that a wetter mix may be employed. This may be along the line of so-called "stripper" machines, the units standing with webs and cores vertical. Such equipment now available produces only plain units—none with a special facing mixture. Tamped products will undoubtedly be improved by tamping the concrete in thinner layers than does most available equipment, and by a combination of tamping and pressing over the whole surface so that the tamper bars will not churn and displace more than they compress.

The wet cast product can be improved by less water and by more thorough mixing. Longer and more thorough mixing produces a mixture more easily placed than one with an excess of water and inadequate mixing. The rule should be: *subtract* water and *add* mixing. Within certain limits the same plasticity, the same flowing quality, can be obtained with less water. An excess of water and inadequate mixing frequently give a concrete in which the ingredients separate—water and cement separating from the sand and stone.

The smoothest flowing concrete in the products field is necessary in the manufacture of concrete stone cast in sand molds.

It is common to let the drum of the mixer turn for a minimum of 5 min; and then to transfer the batch to a mechanical agitator (which is really another mixer) suspended from a crane, which moves about the casting room where the sand molds are filled. The batch or a portion of it is frequently mixed continuously for 15 to 20 min. before being deposited. The concrete so mixed is almost fluid, but extremely homogeneous, excess water being at a minimum and almost unobservable. When poured, ½-in. stone does not settle, but remains in suspension and but little water comes to the top. When poured into molds it flattens out on top slowly and smoothly and not in a soupy rush. In spite of progress in the use of less water in necessarily wet concrete, it should be realized that this is *not* the ideal mix.

Good building units, suitable for creditable construction and showing qualities under tests for both strength and absorption which are satisfactory under rigorous building regulations, can be made and are made with each one of the three types of equipment,—tamping, pressure, and wet cast. Specifications in general are less insistent on high strengths and recognize other qualities as important. Sufficient strength and density to avoid friability and excessive breakage in handling is generally considered sufficient for the common uses of the product. Lightweight aggregates have tended to increase porosity while reducing capilarity and have contributed valuable insulating qualities, more valuable in many uses than high strength.

158. Standard Concrete Stone Units.—Concrete block as usually made in standard machine or multiple mold equipment are usually from 8 to 12 in. thick, 8 to 12 in. high, and 16 to 32 in. long. The 8 × 8 × 16-in. block are the most common. Practically all the machines in common use making building block, turn out products that have one or more hollow spaces. The value of the hollow space lies in the fact that it economizes material, giving a product of much less weight than would be possible if made solid, and in the fact that it provides, as laid up in the wall, a series of air ducts which are valuable as insulation.

Going still further in the development of the idea of air space in the wall, machinery is available to produce so-called two-piece block to be laid up in a wall in such a way as to produce a maximum of air space and yet with systematic bond of concrete between the two faces of the wall.

In addition there are structural tile—light, thin-walled, hollow units, which are manufactured rapidly on power equipment. The standard unit is commonly 5 × 8 × 12 in. It provides a ready hand hold; lays up rapidly, each unit replacing approximately six brick; saves mortar and, having thin webs and walls, is lighter to transport

and to place. Its increasing use has been due to better-quality control methods which have put enough quality into the material in thin sections to withstand breakage in shipping and handling.

Some localities have shown a good market for concrete brick, both common and faced in color, but the manufacture and use of concrete brick is not as yet widespread.

159. Materials.—While any standard Portland cement is generally considered suitable for concrete building unit manufacture, there has, in recent years, been a strong preference among some products manufacturers for cement from certain mills. The block manufacturer has been more concerned about 24-hr. strengths than 28-day strengths. While uniformity at the end of the longer period was expected, certain cements were found to gain their strength more rapidly than others, and in the handling of small units early strength is important. It has been found important, too, that a cement develop a certain condition of adhesiveness in a minimum time after wetting, a quality which favors successful molding by the tamp method. It can no longer be said, therefore, that any standard Portland cement will meet with equal satisfaction the requirements of high-speed building unit production.

Aggregate, besides conforming to the usual specifications as to cleanness, hardness, and character of grading, is more strictly limited as to maximum size than in the usual field work. This is true not only because aggregate should not be larger than one-half the smallest section of the product, but the size is further limited by the molding processes, large aggregates showing a tendency to fall out of fresh products by the tamp process and a tendency to excessive segregation in the wetter mixes. In addition, aggregate is chosen for its surface color and texture value in products subjected to any special surface treatment where the aggregate is exposed to removal of the covering film of cement.

Besides gravel, crushed stone, and slag as acceptable aggregates, the use of cinders has marked an outstanding development in the concrete building unit field. Selected cinders are now extensively used, after passing through crushing rolls, as a complete aggregate. Cinder concrete, being highly cellular, is light, reducing handling costs and providing good thermal insulating quality; is of low capilarity, nailable, greatly simplifying construction; provides good mortar and stucco bond; and is shown by tests to be highly fire resistant. While the strength of most cinder units is less than that in which gravel or stone aggregate is used, the strength is ample for many uses when good manufacturing control is exercised. The increasing popularity of cinder concrete products has resulted in the development of competing light-weight cellular material—notably burned clay.

160. Trim Stone and Ornamental Work from Special Molds.—The manufacture of trim stone or architectural stone and ornamental objects used in connection with building construction or as garden appurtenances to residential architecture is a separate and distinct field of work from that involved in making standard building units of any one of the various block types.

The architect or other prospective user of concrete architectural stone will find, if he looks into the matter of its production, that there can scarcely be said to be a standard product. In various localities, from various factories the range of quality is very wide. The character of the product varies from concrete trim stone of the very highest quality, not infrequently specified for work of a character which it was once thought could be maintained only with marble or granite, to the dullest and most highly friable and absorptive products—variation not merely in appearance but in the structural quality of the stone—some of it very dense, hard, and with the cleanest, sharpest arises and other products porous, friable and ragged at the edges.

It is not, therefore, wise always to accept the lowest of a number of competitive bids. If the prospective user has not seen plenty of evidence of the character of the work of the manufacturer whose products he proposes using, he will do well to look into the manufacturer's factory, find out something of his methods, his equipment, and the experience he has had in work of a like character. Big jobs of trim stone production have been let to manufacturers who meant well enough but who were utterly lacking in experience or equipment to produce dimensional casts where the details are intricate. The tentatively adopted specifications of the American Concrete Institute and their later refinement will probably do much to correct a very uneven market.

The experienced manufacturer of concrete trim stone turns out products from molds of wood, metal, plaster, or gelatine as the special problem indicates and this is true even in large factories where the bulk of the production is from sand molds or wood molds.

161. Surfaces.—The architectural surface qualities of concrete stone have been highly developed, but they have not been generally developed. The dead, pasty gray of the ordinary concrete block has been a great drawback to the adoption of the whole field of concrete building units.

It has been assumed and perhaps rightly so, that the common type of concrete building unit was thoroughly representative of the possibilities with the material. Yet there are manufac-

turers producing standard concrete block units with good surface values in both color and texture. They are, however, in the minority.

When architects appreciate fully what is possible in the surface treatment of concrete—as an increasing number of architects are coming to appreciate through the highly developed quality of products in some localities—they will be more keenly aware that it is only for them to specify.

With a world of special aggregates obtainable from which the architect may draw for any kind of color scheme and with numerous methods available for practical use for exposing these aggregates in the face of concrete products, concrete stone has a promising future, due to one feature alone—the feature of absolute control in manufacture.

The surfaces of wet cast stone as it comes from the molds is more pasty and less attractive ordinarily than the surface of products made with a much drier mix and tamped in the molds. This does not apply where special methods are followed to secure a facing of special aggregate that is placed dry and held by the wetter mix put in behind.

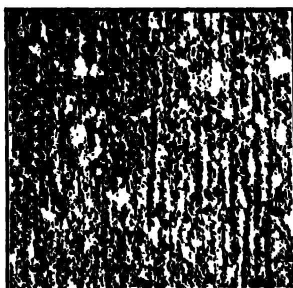


Fig. 62.—An example of fine textured concrete surface obtained by cutting.

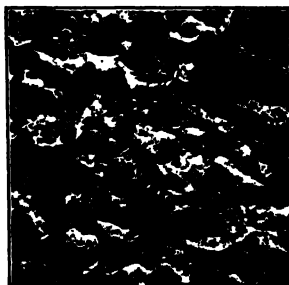


Fig. 63.—Machine-made concrete block with coarse limestone—no facing mixture and very little sand and cement.

Concrete stone made in sand molds must at least be well cleaned up after hardening, as parts of the sand mold are found here and there cemented to the stone. The very least in the way of surface treatment given such products is a thorough rasping and usually a rubbing with an abrasive material.

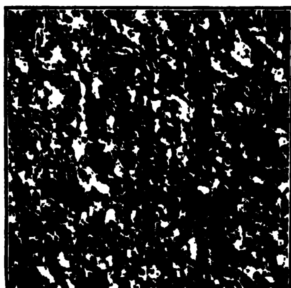


Fig. 64.—A cut concrete stone surface.

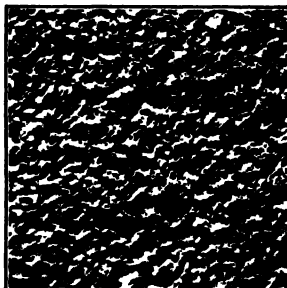


Fig. 65.—Tooled surface of concrete trim stone.

All exposed surfaces of most high-grade sand-cast stone is cut, revealing the aggregate. Stone cutters are employed for the finishing work, using hand or pneumatic tools, bush hammers, picks, etc. Stone with plain flat surfaces are handled by machinery and planed down or cut in fine parallel grooves by revolving discs of carborundum.

Where the aggregate has been graded so as to cover a large percentage of the surface, concrete stone is successfully polished and given a fine gloss by the same methods of grinding, sanding, and rubbing, as are used in the natural stone industry in finishing marble and granite. It must, of course, be considered that it is the stone in the surface that takes the polish and not the cement, so that the success of the result depends a great deal upon the care that has been exercised in getting a mix that will give a high percentage of stone surface.

Most of the high quality stones manufactured by the sand molding method is of the same mixture throughout, but by far the greater portion of concrete trim stone is made by the tamp method and is faced with one mixture and backed up with another. In such work the quantity of special aggregate is relatively small and there are great possibilities for very beautiful effects at a small increase in cost.

Facings as most commonly used are mixtures of gray or white cement with fine sand, either white, buff, or yellow, or with the crushed marble. Most of the surfaces are smooth in mixtures of one part cement to 2, 2½, or 3 parts of fine aggregate. Color is sometimes obtained in the mortar binding the aggregates by the use of mineral color with the cement in small quantities. Such facing mixtures can be vastly improved in two ways: (1) by using coarser facing aggregates to give more rugged texture, more the effect of a material made by binding together with cement a composite product of natural stone; and (2) by such a treatment of resulting surface as will expose aggregates to view.

Most concrete stone has been of cement color and there is no good reason why it should be. The cement is merely a binder, a mineral glue. The beauty lies in the particles which are bound together. The cement may be removed from the exposed surfaces in several ways. One way is to spray tamped products with water when they are first removed from the molds, using a nozzle giving a fine diffused mist, applied however with some force—usually with a pressure of about 40 lb. Care must be exercised not to wash out too much cement and not to leave the face streaked. Some manufacturers do the spraying with the product lying face up on its pallet and others turn the block so that the face is vertical. The former is probably the better way since it has a tendency to drive the cement which is washed off, into the stone, where with the additional water of the spray, a denser matrix is formed for the exposed aggregate.

Another surface treatment is in brushing when the product is from 6 to 24 hr. old, depending upon curing conditions and consequent rapidity of hardening. Experience alone will determine in particular cases the proper time to brush the surface cement away and expose the aggregate to best advantage without dislodging aggregate, and at the same time accomplish the desired result most economically. Brushing may be done with stiff fiber brushes, or with brushes made by clamping together small sheets of wire netting. Much depends upon the character of the face to be brushed. Plenty of water is used while the brushing is in progress. Satisfactory results are more likely to be obtained with rather coarse facing mixtures in which a minimum of sand is used. In other words, only enough mortar should be used in the facing mixture to bind the aggregates, which may vary from fine sand-like particles to pieces of 1-in. size. Many different effects are obtainable with only a small variety of facing aggregates by using different gradings and blendings and combining colors in different sizes. For such work it is not necessary in many cases to go far afield for a facing material. Local stone, crushed, screened, and graded will give excellent results and at the same time lend to the products the advantage of local colorings and characteristics.

Surfaces may be further cleaned and brightened by the use of a wash of commercial muriatic acid and water from 20 to 50 % in strength depending upon the age of the concrete. The older and thicker the cement film, the harder the work the acid must do.

Acid is used a great deal in finishing fine ornamental work and where there are fine lines, care must be exercised that the acid does not eat too far. The action of the acid may be stopped at any time by the application of plenty of water.

In general, the architectural future of concrete lies in better control and a finer technique, along with a realization that it is the aggregate which gives character to the work and that surfaces should be created with reference to the distance from which the surfaces will ordinarily be viewed. The adoption of more rugged surface conceptions increases the usefulness of concrete. Use has been made of crushed ceramics, colored to order previous to burning and graded for each architectural requirement. Upon grading and consequent cutting down of the cement content is dependent the practical elimination of the gray cement factor from the final surface when cleaned.

162. Standards and Specifications.—Building regulations have usually worked on the safe side, requiring much more than necessary. Enforcement, on the contrary, was often lax, so that the excessive requirement lost force. Of recent years, manufacturers of good, uniform-quality building units have seen wisdom in a thoroughgoing cooperation in the enforcement of just building regulations as a protection to their own well-controlled production against loosely operated factories whose inferior products threatened to undermine public confidence.

Through local associations and through the American Concrete Institute there has been an effort by building unit manufacturers to arrive at a standard of quality commensurate with the use of their own and competitive materials and to assist in the maintenance of that standard as the best protection of their enterprises. This sense of responsibility has been a development coming naturally with bigger plant production and larger investments.

Specifications of the American Concrete Institute for concrete block, structural tile and brick will be found in Appendix *E*; and for cast stone in appendix *L*.

These requirements are not, obviously, based on what is possible with concrete but on a practical working minimum to meet a degree of quality which the construction industry has seemed to find sufficient in other long-tried materials.

When concrete units are to be used in the finer types of structures, cast stone is readily made with very high compressive strength and very low absorption.

Strength is not the only important essential. Economic availability is a consideration which keeps the requirements well down toward the actually needful. There has been a tendency, however, to recognise and use materials of very low strength because the strength factor alone seemed ample. In some quarters, this may have gone too far. A 700-lb. concrete may be strong enough, but a concrete low in strength is likely to be friable, porous, and readily disintegrated under severe exposure.

Manufacturers whose processes have been highly developed and whose factory efficiency has been built up to the exactions of high standards should go very slowly in any organized effort to lower the standards of building requirements so that there is no recognition of high-quality products.

While it is unquestionable that the highest standards of quality cannot be attained with equipment designed and utilized for the most rapid production, it is also unquestionable that, with machinery in its present state of development and with the industry's greater knowledge of material proportioning, products *can* be made of vastly higher quality than the average product now made with such equipment.

TERRA COTTA

By D. Knickerbacker Boyd

163. Terra Cotta.—"Terra cotta" is the name properly given to one of the oldest of the time-proven building materials. For a while, this one of the four standard products employed for permanent masonry construction and made of burnt clay, fired at a high temperature, was called "architectural terra cotta." At the same time, hollow building tile was designated as "structural terra cotta." But through common usage and a better understanding of terms, brought about largely through the work of committees of the American Society for Testing Materials, the latter is now thoroughly understood by the name "hollow building tile;" and the subject of this article, by the name "terra cotta" without the word "architectural."

164. Use and Properties of Terra Cotta.—Terra cotta is used for the exterior facades of buildings, as a trim or ornamentation with other masonry, and as an interior decorative material. It is strong, thoroughly fire resistant, has a relatively low absorption, and, when glazed, gives a practically non-absorbent surface for weather exposure. Manufactured of a plastic-clay mixture and largely manually made, it may be molded or modeled to a variety of forms and sizes, given special texture finishes, or glazed with any one or a combination of permanent colors. An almost endless variety of color combinations or shades either in full glaze or in mat finish is available. By a suitable selection of colors and texture, it is particularly effective not only in daylight but also with flood lighting for night-time illumination. Its properties make it ideally adaptable to architectural composition in form and color, and, because of its enduring qualities, when properly designed and erected, it is a building material of high merit. Some of the most charming architectural gems, centuries old, are preserved to present generations in their original terra-cotta forms.

165. Procedure and Characteristics.—Preparatory to the production of terra cotta, the architect's complete scale drawings and steel framing plans are furnished the manufacturer, who, following the design, makes scale shop drawings showing the jointing and construction and full-size details to the proper shrinkage dimensions. The latter are submitted to the architect for approval before proceeding with the work.

In the drying and burning process, all water having been expelled, there is a consequent shrinkage in the size of the pieces—practically 1 in. in 1 ft.—allowance for which is made by the terra-cotta draftsman, who must necessarily re-draw all architectural-scale or full-size details, at what is known as the "shrinkage scale" of 13 in. to the foot.

Full-size models to shrinkage scale are made of plaster for each different shape shown on the shop drawings. Over these models sectional molds of plaster are cast, from which later the required number of pieces of terra cotta are produced.

From the architect's drawings or sketches, in the style and period indicated, the modeled ornament is applied in clay to the face of the plaster models. Photographs of these are submitted to the architect for approval, or he may personally examine them at the factory—the soft clay permits of such corrections or improvements as may be desired.

The mixture of clays and fusible minerals used in forming the terra cotta is carefully selected and proportioned to give the desired degree of plasticity and a composition which, when fired at high temperatures, will produce a homogeneous body, amply strong to carry the required structural loads.

In the manufacture of terra cotta, clays of a high quality must be used, and the proper selection and proportioning of these is of prime importance. Even though the same body is used for all the various colors, finishes, and surfaces, as is the practice in most terra-cotta plants, it is nevertheless seldom that any one locality furnishes all the clays required for a first-class terra-cotta body. A partial vitrification of this body is desirable, but a clay that is too fusible will warp badly in burning. To correct this tendency, at least one of the clays should be a refractory (or fire) clay, and further to insure straightness and control shrinkage, about one-third of the mixture should be of ground burnt clay (technically called "grog").

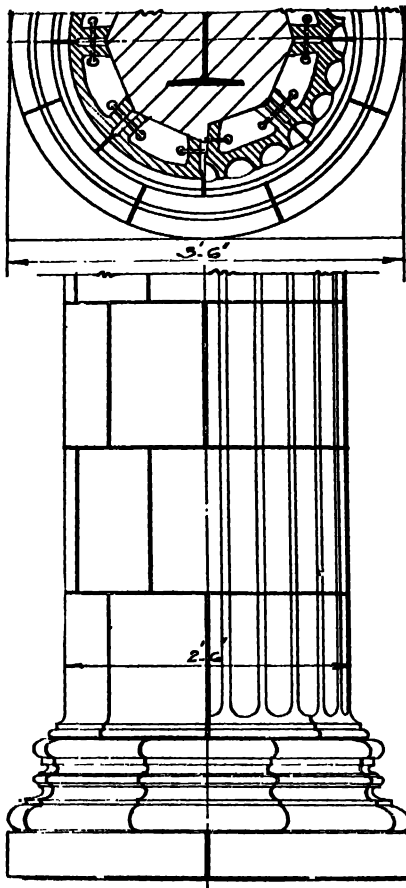


FIG. 66.—Example of column construction.

166. Synopsis of the Manufacture of Terra Cotta.[1]—The foregoing processes are preparatory to actual production, the first step of which is pressing. This is a manual operation and consists of pressing the plastic clay into the mold. The walls of the pieces should not be less than 1 in. thick, following the contour of the mold, and the partitions should be of such thickness and so spaced as to perform their proper functions with regard to form and structure.

To save material and weight, to lessen the tendency to warp, and to assist in drying, the blocks are formed of an outer shell connected and braced by partitions or webs. The width of the spaces formed by the webs is generally about 6 in., but this spacing will vary with the contour and size of the pieces. The outside shell and the partitions should be of uniform thickness ranging from 1 in. in small pieces to at least 1½ in. in large pieces.

Where ornamentation is continuous, proper jointing permits of securing duplication of pieces. A mold may, therefore, be used to press a number of similar pieces, a process less expensive than the separate carving and cutting of individual pieces as is required for other facing materials.

The pressed pieces remain in the mold until the clay stiffens. It is then removed and skilfully retouched before it is placed in driers to evaporate the moisture.

From the drying process, the terra cotta passes into the spraying department, where, by means of compressed-air apparatus, the exposed surfaces are coated with the ceramic mixture which, during the firinpg rocess following, develops into the desired color or glaze.

These colors or glazes are prepared with scrupulous care, according to exact ceramic formulas. The variety of shades and textures which may be obtained opens up an unlimited field of permanent color design in architecture.

Following the coloring process, the terra cotta is fired in kilns where it is subjected to a temperature rising gradually to 2000 deg. F. or more, depending upon the temperature of maturity of the clay and glaze. After proper firing, the kiln is allowed to cool slowly to normal temperature, an operation that causes a slow annealing of the terra cotta.

Terra cotta should be well burnt and should give a sharp metallic ring when struck; a sample or test piece broken in two should show a uniform and homogeneous fracture free from laminations. The body should be hard enough to resist scratching with steel, should be free from fire or body cracks that would impair its strength or durability, and the blocks should not be badly warped or twisted.

[1] Extracted from "Terra Cotta—Standard Construction," published by the National Terra Cotta Society.

Terra cotta is usually fired in periodic muffle kilns. In recent years, the tunnel kiln has been developed. In the latter type, the pieces are set or loaded on cars, which travel through a long, heated tunnel.

From the kiln, the terra cotta is removed to the fitting department, where it is laid out and marked to correspond with the piece numbers shown on the shop drawings. It is also marked to indicate the position it is to occupy in the building. Where required, the joints are squared or cut to proper alignment and size, either by hand or by grinding. Careful fitting is essential to assure satisfactory results in the erected terra cotta.

For rail transportation, terra cotta is usually shipped in bulk, securely packed in hay and braced to prevent shifting.

Upon arrival at the building site, the hay should be removed and the terra cotta placed in the order marked, in piles on wooden strips.

For export by vessel, the terra cotta is usually packed in boxes or crates, according to the special conditions encountered. Another method that has been found to be economical and entirely satisfactory is to ship the terra cotta loose after it has been wrapped and tied in corrugated cardboard.

The appearance of erected terra cotta is greatly affected by inaccurate setting and defective pointing of the mortar joints. As the individual pieces of terra cotta have been carefully fitted and numbered to correspond with the erection drawings, the *pieces must be erected in accordance with the numbers thereon* if satisfactory results are to be secured.

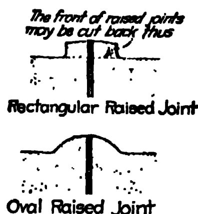


Fig. 67.—Two methods of making raised joints on sloping surfaces.

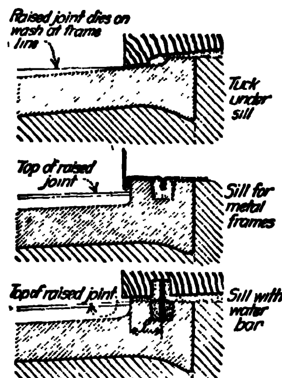


Fig. 68.—Details of sill construction with raised joints and fillets.

167. Surface Finish, Ceramic Finish.—Up to about 30 yr. ago, terra cotta was made in but two colors—unglazed red and unglazed buff— the red being the more widely used, matching the red brick with which it was then most frequently used. At the present time, while the body of all good terra cotta is very much the same, by surface treatment practically every color that may be wanted in architectural work can be obtained. Terra cotta may also be manufactured in any surface texture or finish desired.

While discriminating architects and clients recognize in this sterling product of the ceramic art a quality all its own which should stand on its merits as a facing material, it may be and frequently is made similar in color and texture to the various building stones. Shafts of stone columns are frequently fitted with ornamental caps of terra cotta.

The following are terms usually applied to the various textures and ceramic finishes procurable in terra cotta:[1]

The term "Surface Finish" designates the texture of the surface of the clay body prior to the application of a ceramic finish. It may be smooth, tooled or drove, light irregular drag or combing, heavy irregular drag or combing, or special.

A special surface finish like "bush hammered," "pitted," "vermiculated," etc., involves extra expense and, if required, should be clearly specified. The surface finish for unglazed surfaces may be smooth or may be tooled with a light or heavy drag. Flat surfaces of sufficient width may be tooled, while the curved surfaces of moldings may be left smooth. The surface finish for a glazed ceramic finish (whether lustrous or mat) is usually made smooth. Granite colors, if unglazed, may be made smooth or with irregular drag, or pitted. If a glazed ceramic finish is used for granite colors, the surface treatment is usually smooth.

The term "Ceramic Finish" designates the surface and color applied by a ceramic process of coating, glazing, burning, etc.

Such finishes may be:

An *unglazed terra cotta* which is a ceramic finish producing an unglazed finish made in various shades of buff, gray, salmon, red, and brown. Most colors thus made are vitreous.

[1] Extracted from "Standard Specification for the Manufacture, Furnishing, and Setting of Terra Cotta," adopted by the National Terra Cotta Society.

A *glazed or enameled terra cotta*, which is the term applied to terra cotta having an impervious ceramic finish of a glassy texture which may be either lustrous or mat (sometimes designated as full or dull glazes or enamels) and which may be made in various colors.

A *granite-color terra cotta*, which may be either an unglazed granite color, which produces a mottled ceramic finish similar to unpolished granite, or a glazed or enameled granite color, which is a mottled ceramic finish similar to polished granite and made either lustrous or mat.

A *polychrome terra cotta or faience*, which designates a ceramic finish having two or more colors on the same piece and which may be an unglazed polychrome (unglazed terra cotta having two or more colors on the same piece); a glazed polychrome (glazed terra cotta having two or more colors on the same piece); or a blended-color polychrome (made only in glazed terra cotta), which designates the ceramic finish in which the separate colors are not defined by definite lines or contours of ornaments but are to be blended by brush treatment or the like.

Fire gilding, which is a coating of gold glaze, either mat or lustrous, fixed by an additional burning.

There are a number of ceramic finishes used by individual manufacturers, the processes for which are patented or the names copyrighted, which are not mentioned here.

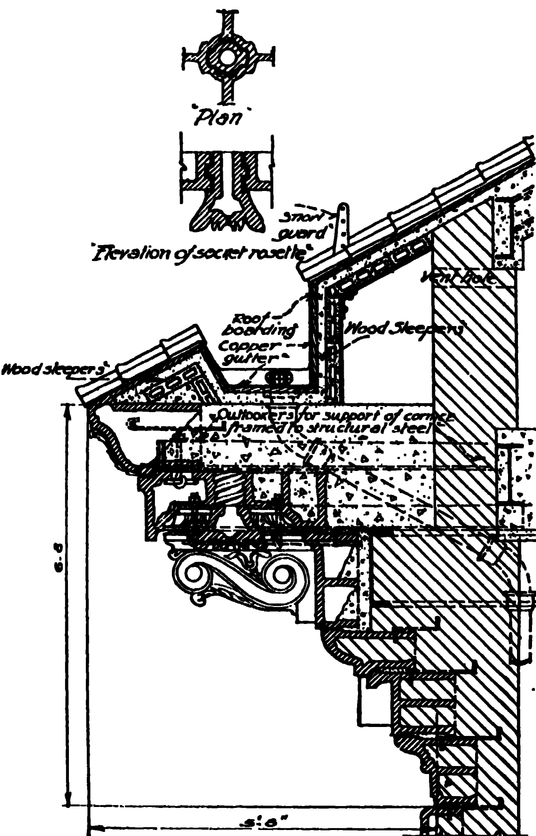


FIG. 69.—Section through cornice and gutter showing method of support and anchorage.

168. General Principles for Construction in Terra Cotta.—All building materials give their best services in permanency when they are used with a proper knowledge of their properties and possibilities. Their application to any building produces results, therefore, in direct proportion to the care exercised to secure proper and adequate construction.

In concrete or steel-frame buildings, the terra-cotta facing should be fully and continuously supported at each floor level on shelf supports of adequate strength and stiffness, rigidly connected to the structural frame. Steel shelf angles or supports, in all cases, should be located in mortar joints. The strength of the terra cotta should not be unnecessarily reduced by cutting the webs to receive the steel.

Proper provision should be made for expansion joints, at shelf supports, over column caps, etc., to prevent the development of disruptive stresses caused by deflection, wind pressure, temperature changes, settlement, and like forces.

The volume changes incident to the setting and hardening of concrete, and the variations in volume of concrete due to humidity and temperature conditions, require provisions to allow free movement of the supporting frame and may make it undesirable to fill completely a facing applied to a concrete structure.

Proper care should be exercised to prevent the corrosion of all steel supports, ties, etc. Where such protection cannot be permanently secured through encasement with mortar or concrete, or through the use of corrosion-resistant metallic coatings, non-corrosive metals should be employed.

Exposed free-standing construction, subject to the absorption of water through mortar joints and liable to injury from subsequent freezing or the expansion of improper filling material, should generally be left unfilled and should be ventilated by means of weep holes.

Properly constructed flashing should be provided to cover the top of large projecting horizontal courses, the backs and tops of parapet walls, wide-exposed sill courses, etc., and all projecting features should have drips.

Sills should have a raised fillet at the back to be let into a groove in the wooden sill or should have a reglet for metal water bar. Ornamental work, where, on account of the character of the detail, pockets are formed in which

water, snow, or ice can collect should be provided with holes or washes for drainage. Copings, sills, and projecting members, generally, should be provided with drips, and parapets, cornices, and similar unfilled courses should be fully ventilated by the use of weep holes.

Wide, flat washes in terra cotta, where it is impractical to use a sufficiently steep pitch for readily shedding the water, should be covered with copper flashing. Sufficient width of copper must be allowed for covering the entire

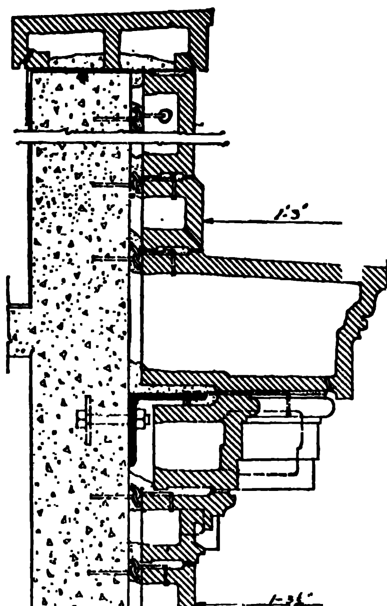


Fig. 70.—Section through cornice parapet and coping.

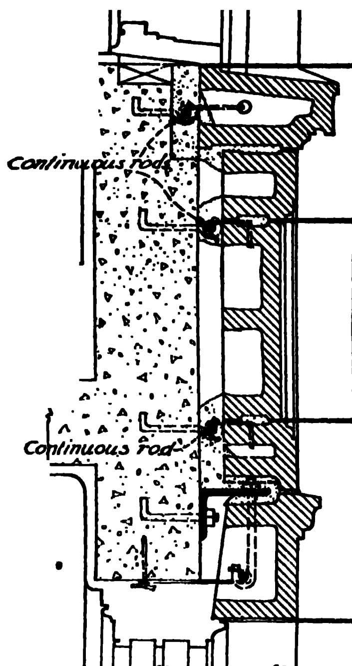


Fig. 71.—Section through lintel panel and sill.

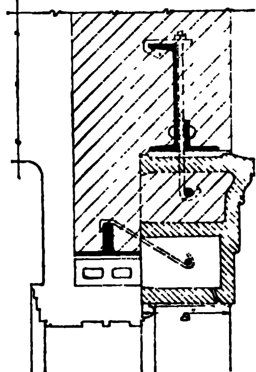


Fig. 72.—Section through soffit and lintel over window opening.

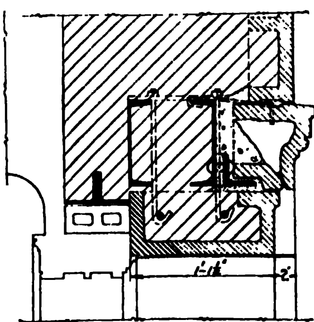


Fig. 73.—Section through soffit and lintel forming part of terra cotta facing.

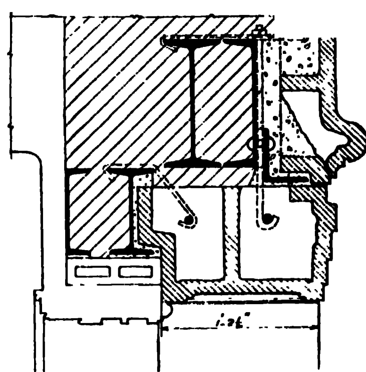


Fig. 74.—Section through soffit and lintel.

width of the wash and, with the back edge of the copper tucked into a joint or groove, properly located according to the particular case, so that there will be no possibility of seepage of water into the structure. All flashing metal should be laid with proper provisions for expansion and contraction of the metal. This flashing method should be used in every case where the wash pitches inward toward the structure and stops against any superimposed work, such as walls of stories above, parapet balustrading, parapet walls, etc. In no case should gutter grades be formed in terra cotta. Structural tile, cement, or concrete should be used to form the grade, and this, in turn, covered with metal and drained.

169. Setting Terra Cotta. Terra cotta is set by the mason contractor or by the manufacturer. The terra cotta for the various portions of the work should be assembled at the

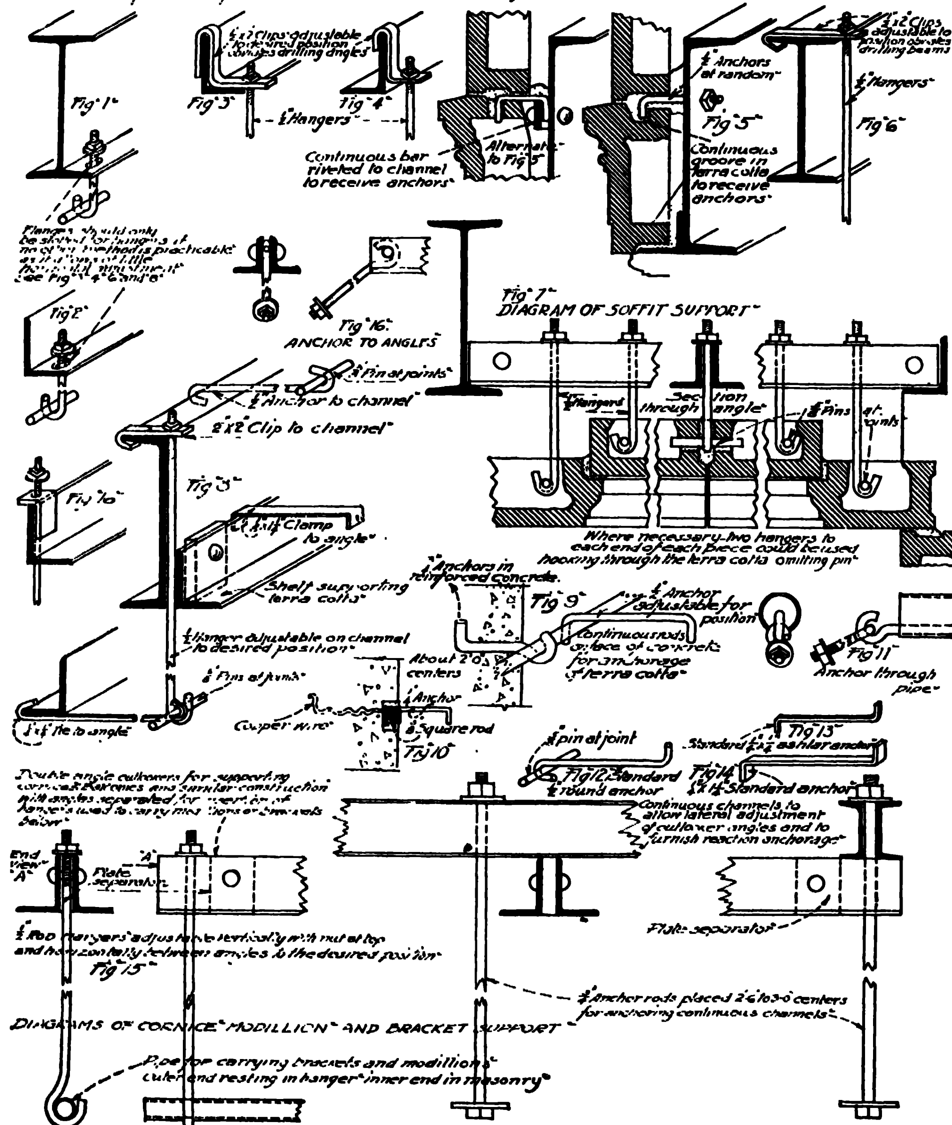


FIG. 75.—Details of iron anchors, hangers, straps, clips, etc., used in setting architectural terra cotta. Figure numbers are for reference to these several parts.

building, and the sizes checked off so as to verify the joint allowance and guard against variations which might have occurred in the framework or superstructure of the building as thus far erected.

The work should be anchored to the backing and hung or secured to the structural frame, as indicated on the setting drawings.

Anchors for securing terra cotta in place are furnished either by the terra-cotta manufacturing or by the contractor for the erection of the work. When the setting contractor furnishes the anchors, etc., it is generally customary for the manufacturer, on the completion and approval of the setting drawings, to give to the setting contractor a schedule of the size and number of all anchors, clamps, dowels, hangers, brackets, and special work necessary securely to anchor the terra cotta to the masonry backing and to the structural frame and to support any projecting pieces.

Heavy projecting courses, whether supported by metal or not, should be well shored up from the exterior until the work on top of these courses is placed to a sufficient height.

All terra-cotta projecting courses should be so set that the arris casting a shadow is true to line.

170. Jointing and Pointing.—All terra cotta should be set true to a line and carefully laid in a solid bed of mortar. All rebates in bed and cross-joints from front to back and top to bottom should be filled solid with mortar, leaving no voids. Each piece of terra cotta should be tamped into place, excess mortar cut off and struck with a jointer or trowel. All sills, wall copings, and other capping courses should be set in a thick bed of mortar and well pounded down so that the mortar fills all spaces around bottom of webs of terra cotta.

All mortar for setting and pointing should be composed of 1 volume of Portland cement to 3 volumes of sand. Hydrated lime, not to exceed 9 lb. to the sack of cement, may be added.

All joints in terra cotta should be pointed and struck as the setting progresses, except in freezing weather. In freezing weather and when re-pointing is necessary, all joints should be raked or cut out to a depth of ½ in., and the pointing mortar driven into the joint and struck with a jointing tool.

The vertical joints of copings should be filled with waterproof cement.

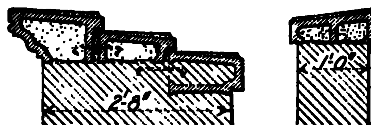
All joints in overhanging terra cotta, balustrades, parapets, and free-standing features should have joints raked out ½ in. and pointed with an approved elastic cement.

When plastic cements are used for expansion joints, the bed joints for their full depth should be filled with the plastic material. Filling the front ½ to ¾ in. of a raked-out joint with a plastic cement and leaving a hard mortar backing in the rest of the joint cannot be considered a proper construction for an expansion joint.

171. Cleaning.—On completion of the work and after all mason's wedges and all centering are removed, and after pointing and re-pointing all joints wherever necessary, the surface of the terra cotta should be cleaned with water and a good abrasive soap or washing powder, using sufficient force in scrubbing to remove all stains. Any hard lumps of mortar may be removed by the use of a sharpened hardwood stick. Steel brushes, chisels, or other metal tools which might damage the surface by scratching, chipping, or discoloration with rust stains should not be allowed.

If satisfactory results cannot be obtained by the use of abrasive soap or washing powder, a solution consisting of 1½ pints of muriatic acid to a gallon of water may be used. In the use of acid solutions, only wooden pails and fiber brushes should be employed.

172. Maintenance.— The exterior surfacing of buildings is expected to be impervious to the infiltration of moisture. The contraction of the mortar in joints, vibration, and the disintegration of the mortar by frost will, from time to time, develop cracks, etc., which will permit leakage of surface moisture to the interior unless proper maintenance provisions are carried out. The exterior of all buildings should be periodically inspected, loose mortar joints raked out and repointed, reglets for flashing kept filled, waterproof joints should be properly maintained, drainage systems kept open, and all flashings kept in proper repair. The ease with which the ceramic finish of a terra-cotta facade may be cleaned, by a simple washing, suggests, also, that the value of the beauty and the light-reflecting qualities of terra cotta as a building material should be maintaned by a periodic cleaning of the structure.



Copings for walls up to 13 in. in thickness may be safely made in one piece, for walls 13 to 28 in. in thickness in two pieces, and for walls above 28 in. in thickness, in three or more pieces as required.

Fig. 76.

TILING

By D. Knickerbacker Boyd

The word "tile" has its origin in the Anglo-saxon *tigel* which, in turn, is a derivative of the Latin *tegula*, from *tego*—to cover. Although since appropriated to designate other products made in all sorts of shapes and from all kinds of raw materials, the term "tile" without other qualifying words or phrases still properly applies to those examples of the ceramic art which are used as a surfacing or finish for floors, walls, and ceilings, and in mural decoration on the interior or exterior of buildings.

173. Manufacture of Tiles.—Tile are made from different kinds of clays, feldspar, and flints obtained from domestic banks and quarries or imported from other countries. These raw materials undergo a variety of refining and mixing processes before they become suitable for forming or pressing into tiles. According to the process used, tile makers distinguish between tiles made from the materials in the plastic state and those pressed by means of machinery from the pulverized and practically dry materials—the "dust." Thus, in the one case the tiles are "made plastic," in the other case they are "dust-pressed."

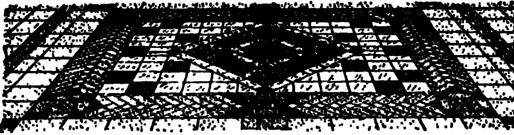


Fig. 77.—Illustrating decorative uses of floor tile.

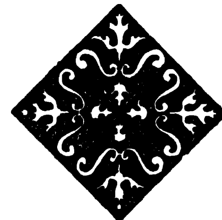


Fig. 78.—An example of inlaid, or encaustic tile

174. Unglazed Tiles.—Unglazed tiles are produced in one firing which brings them direct to their ultimate degree of vitrification, color and surface texture. The colors in these unglazed tiles are produced either by the selection of clays that will burn to the desired color, or by the addition of certain oxides, such as the oxides of cobalt, chromium, etc. It lies in the nature of the raw materials and color ingredients that some of these tiles can be fired to complete vitrification, while others do not permit this. Consequently, the unglazed tiles are divided into "vitreous" and "semi-vitreous."

The vitreous colors in unglazed tiles include white, silver gray, celadon, green, blue green, light blue, dark blue, pink, cream and so-called "granites" of these colors. The semi-vitreous colors comprise buff, salmon, light gray, dark gray, red, chocolate, black, and "granites" of these colors.

The trade terms flint, quarry, paving, esplanade, corrugated, hydraulic, chipped face tiles ceramic mosaic, etc., designate the various kinds of unglazed tiles made for different uses and decorative effects.

The principal shapes and sizes in which unglazed tiles are manufactured are:

Square, inches	Oblong		Octagon	Hexagon
9 × 9	9 × 4½	4¼ × 2⅛	6 × 6	6 × 5 3/16
6 × 6	9 × 3	4¼ × 1¼	4¼ × 4¼	4¼ × 3 11/16
4¼ × 4¼	6 × 4	3 × 1½	3 × 3	3 15/32 × 3
3 × 3	6 × 3	3 × 1		2 5/16 × 2
2⅛ × 2⅛	6 × 2	3 × ½		6 × 3
1½ × 1½	6 × 1½	2⅛ × 1¼	**Triangle**	4⅛ × 2⅛
1 1/16 × 1 1/16	6 × 1	1 1/16 × ½	3	
	6 × ¾		1 47/64	
	6 × ½		1 5/32	

Encaustic tiles is a term that strictly belongs to "inlaid" tiles. These are decorative tiles produced by inlaying a figure or ornament of one color into a body of a contrasting color before firing. They are vitreous or semi-vitreous according to the colors used. The word "encaustic" is frequently misapplied as a general term for tiles; it has however, no descriptive significance except in connection with inlaid tiles.

Ceramic mosaic is a trade designation that refers to the smaller sizes of unglazed tile, which for expediency in setting are also marketed "mounted" with the face glued to sheets of paper. This paper is soaked and removed after the tiles have been set. Ceramic mosaic is also made with a glazed surface and in many colors. (For sizes of unglazed ceramic mosaic and of mounting sheets, see Grades of Tiles.)

The thickness of these unglazed tiles varies with size and kind, the larger sizes and shapes having a thickness of from ½ to 1 in., while ceramic mosaics are usually ¼ in. thick.

175. Glazed Tiles.—Glazed tiles are made from essentially the same materials and by the same processes as the unglazed tiles, except that they require two firings. The first firing produces the "biscuit," "bisque" or "body" made either plastic or by the dust-pressed method. This bisque is subsequently coated with the "glazing" liquid, made from pulverized clay, feldspar, flint, and a flux. The bisques are then again placed in the kilns and subjected to high temperatures which unite glaze and bisque.

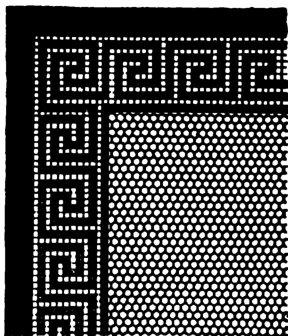


Fig. 79.—Ceramic-mosaic floor, plain field with border.

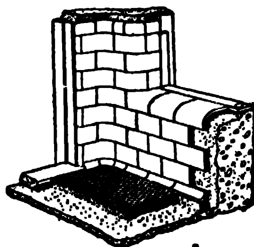


Fig. 80.—Rectangular glazed wall tile, round ceramic-mosaic floor tile, separate cove and "woven" combination tile at internal angle and at window.

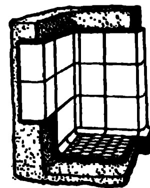


Fig. 81.—Square glazed wall tile, octagonal vitreous floor tile, separate cove at floor, and at internal angle. Quarter round at corner.

Trade custom has established the application of the word "glazed" as an exclusive designation for *white* glazed tiles, while the same kind of tiles in color are known by the term "enamels." Thus, the white tiles generally used for wainscot in bathrooms are "glazed" tiles, and tiles with a colored glaze are "enamels."

The range of colors and tints in enamels is practically unlimited and the textures are of the greatest variety. Virtually any color can be procured in enamels. Moreover, they are made "plain" or "mottled" in one or more colors.

Both glazed tiles and enamels are produced in bright, matt, and semi-matt or dull finish; that is to say, the bright have a surface of high gloss, the matt are entirely devoid of gloss, and the semi-matt or dull finish applies to all finishes intermediate between these extremes.

Glazed tiles and enamels are made in the following regular sizes and shapes (see Art. 177 for standard sizes of white glazed tiles):

Square, inches	Oblong		Hexagon
6 × 6	9 × 6	4¼ × 2⅛	3 × 3 15/32
4¼ × 4¼	9 × 4½	3 × 1½	2 × 2 5/16
3 × 3	9 × 3	3 × 1	2 5/16 × 2 21/32
2⅛ × 2⅛	6 × 3	3 × ½	
1½ × 1½	6 × 2	3 × ¼	
1 1/16 × 1 1/16	6 × 1½	2⅛ × 1 1/16	
¾ × ¾	6 × 1		**Octagon**
½ × ½	6 × ¾		3 × 3
	6 × ½		

176. Trim Tiles.—For use as bases, caps, corners, moldings, door and window trim, etc., certain shaped tiles are made to match the unglazed or glazed field or body of tilework, which

are designated by the terms *trim* or *trimmers*. The range of shapes obtainable in these trimmers is quite extensive and meets any utilitarian or decorative demand.

The term *faience* is applied to comparatively rough glazed tiles made plastic and glazed with enamels of various textures. Any special design or color effect can be carried out in faience and it is especially adapted to the decorative treatment of interior and exterior wall surfaces.

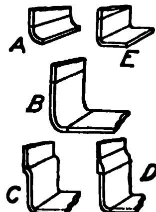


Fig. 82.—Types of cove bases, A and E being those referred to as desirable in wood construction. A is also used as cove in internal angles and is especially desirable in wood construction where shrinkage might occur.

177. Grades of Tile.—Tiles are not manufactured in predetermined grades or qualities. The object of the makers is to produce but one grade, i.e., the highest quality. But due to limitations in the processes and the difficulty of absolute control in firing conditions, certain variations in shades, sizes, etc., take place which are inherent to tile manufacture. The tile makers therefore sort the tiles after they come from the kilns into different grades which experience has established as expedient. With respect to wearing and sanitary qualities no difference exists in these tiles, and appearance, size, warpage, surface blemishes, etc., alone are the basis for the sorting.

The white glazed wall tiles are graded as explained below and marketed in three grades or qualities—*viz.*, "selected," "standard," and "commercial"—and each grade has its legitimate uses. As the term implies, the standard grade is the one used in the general run of work, such as in barber shops, cafeterias, hotels and apartment house bath rooms, moderate priced residences, etc. This grade practically represents the tiles as they come from the kiln, sorted however for uniformity in size. For the selected and commercial qualities, the tiles, as they come from the kilns, are divided into two grades. The tiles that are as nearly perfect as is possible to manufacture are chosen and marketed as selected for use in the finest classes of tilework, such as in high class residential work, operating rooms in hospitals, etc., while the remainder are offered as the commercial grade. This commercial grade finds extensive use where economy, service, sanitation, and light reflecting qualities are required and where manufacturing blemishes are of secondary importance, such as in manufacturing establishments, basement toilets, linings of shafts, etc.

The enamels, vitreous tiles, and ceramic mosaic are marketed in two grades—*viz.*, selected and commercial—and the semi-vitreous tiles in one grade only, selected.

177a. Standards for White Glazed Tiles and Unglazed Ceramic Mosaic.—In accordance with the unanimous action, on October 27, [illegible], of a general conference of representatives of manufacturers, dealers, contractors, architects, and users, the Department of Commerce, through the Bureau of Standards, recommended the establishment of the following standards for white glazed tile and unglazed ceramic mosaic, all of which appears in Simplified Practice Recommendation No. 61.

Sizes of White Glazed Tiles, Inches

6 × 6	6 × 3	4¼ × 4¼

Sizes of Ceramic Mosaic, Inches

Square	11/32, 15/32, ¾, 1 1/16, 2 3/16
Oblong	½ × 1 1/16, ¾ × 1 9/16, 1 1/16 × 2 3/16
Hexagon	1, 1¼

Mounting Sheets and Paper Sizes for Ceramic Mosaic

Size of tile	Size of sheet, number of rows		Size of paper, inches
	Width	Length	
15/32 square	21 × 48 rows		13 1/8 × 26 1/4
3/4 square	16 × 32 rows		12 1/2 × 25 1/4
1 1/16 square	12 × 24[1]		13 1/8 × 26 1/4
2 3/16 square	6 × 12[2]		13 1/8 × 26 1/4
1 1/16 × 1/2 oblong	21 × 24[3]		13 1/8 × 26 1/4
1 1/16 × 1/2 herringbone diagonal	16 × 32		12 1/2 × 25 1/4
1 9/16 × 3/4 oblong	16 × 16[4]		12 1/2 × 25 1/4
1 9/16 × 3/4 herringbone diagonal	11 × 22		12 1/4 × 24 1/2
2 3/16 × 1 1/16 oblong	12 × 12[5]		13 1/8 × 26 1/4
2 3/16 × 1 1/16 herringbone diagonal	8 × 16		11 3/4 × 23 3/4
1-in hexagon	12 × 24		10 1/4 × 24 1/2
1 1/4 hexagon	12 × 18		12 1/2 × 22 3/8

[1] Mounted by itself or in combination with 1 1/16 × 1/2 and 15/32 squares.
[2] Mounted by itself or in combination with 2 3/16 × 1 1/16, 1 1/16 × 1 1/16, 1 1/16 × 1/2, and 15/32 squares.
[3] Mounted by itself or in combination with 15/32 squares.
[4] Mounted by itself or in combination with 3/4 squares and 11/32 dot.
[5] Mounted by itself or in combination with 1 1/16 × 1 1/16, 1 1/16 × 1/2, and 15/32 squares.

Uniform Grade Nomenclature

White glazed tiles ... Selected, standard, commercial.
Ceramic mosaic ... Selected, commercial.

Minimum Grade Specifications

For flat white bright glazed tiles			For unglazed ceramic mosaic	
Selected	Standard	Commercial	Selected	Commercial
The tile of this grade are as perfect as it is possible to manufacture; they are free from warpage exceeding two-tenths of 1 %, wedging and crooked edge exceeding three-tenths of 1 %, and free from specks, spots, blots, pulls, biscuit cracks, biscuit chips, shivered edges, welts, dry spots, scum, sand, and stickers	The tile of this grade are reasonably straight and true in shape and without objectionable surface blemishes. They are free from warpage exceeding four-tenths of 1 %, wedging or crooked edge exceeding five-tenths of 1 %, and free from spots, blots, biscuit cracks, biscuit chips, shivered edges, welts, dry spots, scum, or stickers. The grade permits of certain minor surface blemishes such as occasional specks, sand, and pull	The tile of this grade permit of all of the blemishes and defects which are not permissible in the higher grades but are free from blots and biscuit cracks	Tiles of this grade are as perfect as it is possible to manufacture. They are harmonious in color, easily cleaned, uniformly mounted, and of uniform surface and texture. The vitreous colors are fired to vitrification. The semi-vitreous colors are fired to a degree of vitrification as high as the particular color permits	This grade of ceramic mosaic does not represent the same degree of perfection as the selected grade. Variations and irregularities in textures, surfaces, edges, firing, or combinations of these variations are in evidence. They are, however, satisfactory for some installations
Grade tolerances: A tolerance of 5 % of standard grade tiles in selected and of 5 % of commercial grade tile in standard is permissible.			Grade tolerances: A tolerance of 5 % of commercial grade tiles in selected is permissible.	

	Warpage, per cent	Crooked sides, per cent	Wedging, per cent	Specks	Spots	Blots	Pulls	Biscuit cracks	Biscuit chips	Shivered edge	Welts	Dry spots	Scum	Sand	Stickers
Selected	Less than 0.2	Less than 0.4	Less than 0.4	None	None	None	None	None	None	None	None	None	None	None	None
Standard	Less than 0.4	Less than 0.5	Less than 0.5	Occasional	None	None	Occasional	None	None	None	None	None	None	Occasional	None
Commercial	More than 0.4	More than 0.5	More than 0.5	Allowed	Allowed	None	Allowed	None	Allowed	Allowed	Allowed	Allowed	Allowed	Allowed	Allowed

GRADE DESIGNATIONS

White glazed tiles			Ceramic mosaic	
Across the head and bottom of barrels or boxes is affixed a colored package seal imprinted with the grade name. The colors of the seals are:			The grade for ceramic mosaic is designated by the color and imprint of the mounting paper. The colors are:	
For selected grade, *pink*	For standard grade, *blue*	For commercial grade, *yellow*	For selected grade, *pink*	For commercial grade, *yellow*

Explanation of Terms Used in Grade Specifications

For White Bright Glazed Tiles

Warpage.—A surface curvature, either convex or concave, measured on the face of the tiles along the edges. The degree of warpage is the variation from the plane expressed in percentage of the tile length.

Crooked Sides.—A curvature of the sides, either convex or concave, measured along the sides. The degree of crooking is the departure from the straight line drawn between two corners, expressed in percentage of the tile length.

Wedging.—A difference in the length of two opposite sides, expressed in percentage of the tile length.

Specks.—Any dark dot on the face less than 1/64 in. in diameter and noticeable at a distance of more than 3 ft.

Spots.—Any dark dot on the face more than 1/64 in. in diameter.

Blots.—Green marks or stains on the face.

Pulls.—Small depressions or scratches in the body noticeable through the glaze at a distance of more than 3 ft.

Biscuit Cracks.—Any fracture in the body of the tile visible both on face and back.

Biscuit Chips.—A glazed-over chip on the edge or corner of the body.

Shivered. Edge.—A minute fracture of the glaze running along the edge which appears as a fine silvery thread when struck by light from an angle.

Welts.—An unusually heavy accumulation of glaze in the form of a ridge along the edge.

Dry Spots.—Small areas on the face which have been insufficiently glazed.

Scum.—Lack of glaze, crystalline or frosted in effect, appearing on the face of the tile.

Sand.—Grains of sand embedded in the glaze.

Stickers.—Small rough or raised spots in the glaze.

Certification of Grades

The adoption of minimum grade specifications will be greatly facilitated by the use of a uniform method for certification of grades. Based upon definite grade specifications, the certification of grades will be more effective than the present method of certification by grade name without definition.

Certification shall consist of (a) package grade certificate and (b) master grade certificate. Minimum grade specification and the grade of tile are to be given on both forms.

Grade certificates to be placed in container before closing and affixation of grade seal.

Master grade certificate to be issued to tile contractors on request only and to be used for certifying shipments consisting of one or more grades.

178. Crazing.—In former years some manufacturers were occasionally willing to guarantee glazed or enamel tiles against crazing and some specifications even today call for tiles to be guaranteed non-crazing. This however, is no longer done by any of the large producers who are bound to recognize the limitations of the ceramic art and realize that crazing (or crackling) of any glazed surface cannot be absolutely guarded against.

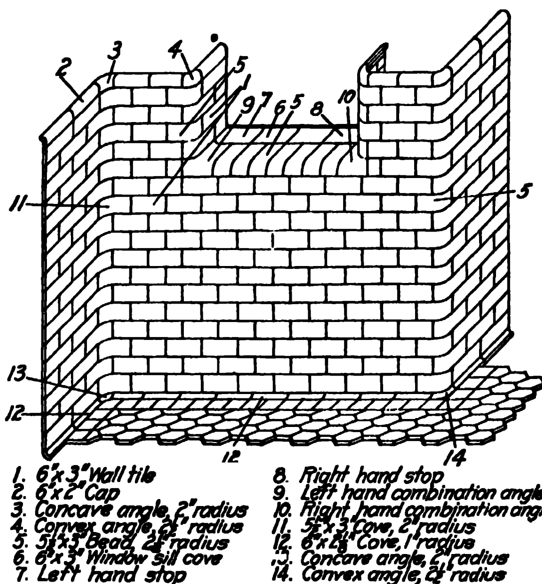


Fig. 83.—Illustrating some of the "Trimmers" made for glazed wall tile, with key numbers.

One of the causes of the phenomena known as crazing is considered to be the slightest kind of a difference in the coefficients of expansion between the materials comprising the body and those of the glaze, which most frequently does not manifest itself until after the tile are laid. This may or may not assert itself until years after the tile are laid and sometimes will occur where the sun shines on the tile or in the proximity of radiators, while not appearing elsewhere in the same piece of work.

The foregoing remarks refer principally to bright glaze finishes on any tile. In the finest decorative tiles, in faience, and in other finishes, the craze, like that of the surface effect produced by the crackled finish of the finest ceramic work, is regarded with favor.

179. Setting of Tile.—Particular attention should be paid to the methods employed to overcome shrinkage of woodwork when bathrooms or other places are to be tiled in buildings of frame construction—or in any type of building with wood joists. Interior partitions should be located over those below and, where this is not possible, steel beams should be used to support the partitions surrounding bath rooms or other tile places so that no greater shrinkage will occur than at the outside walls. With such construction, lighter weight joists may be used, especially under the tile floors, assuring better seasoning and less shrinkage as well. In addition to insuring the tile work against the effects of settlement, this type of construction, through saving of labor in doubling trimmers and headers, bevelling of joists, cutting in floor boards, etc., will be found to have its economics, compensating for the increase due to the introduction of steel in place of wood where indicated.

In the case of wood construction because of inevitable shrinkage it is recommended that if coves are to be used at floor angles they be in the form of combination tile on the floor tile and not on the wall tiles; also, that internal corners, if cove, be made either with separate coves or with straight joints on the combination tiles. The latter should not be alternated or woven in wood construction as any settlement or shrinkage will break the tile. These precautions do not of course apply in the case of fire resistive construction where floors and partitions are of concrete, hollow tile, or masonry, or encased steel construction. In these types of construction full range of choice in the "tile trim" may be resorted to.

For comprehensive descriptions of the materials and processes entering into the manufacture of tiles see "Basic Information on Tiles," and for complete specifications on the application of tiles to all types of construction, as in a composite building, see "Basic Specification for Tilework," each issued by the Associated Tile Manufacturers, New York City.

GLASS AND GLAZING

By LeRoy E. Kern

180. Raw Materials.—The principal raw materials used in the manufacture of glass for general glazing purposes are: silica (white sand), lime (limestone), soda (soda ash), charcoal, cullet (broken glass), a small quantity of alumina bearing material, and possibly decolorizing agents. These are mixed in large earthenware pots and fused at a temperature of about 3000 deg. F.

181. Physical Properties of Glass.—The composition and physical properties of glass are widely variable, not only in different varieties of glass, but also in different makes of the same type or kind of glass. Neither the mixing formulas nor the conditions of manufacture have ever been standardized and no general text book on the selection of grades or materials has been issued in this country. The results of tests made to determine the physical qualities of glass have differed greatly as is indicated by the following table:

Table of Physical Properties of Glass

Tensile strength	2,000 to 10,000 lb. per sq. in.
Modulus of rupture	3,000 to 4,000 lb. per sq. in.
Modulus of elasticity	10,000,000 to 11,000,000 lb. per sq. in.
Crushing strength	6,000 to 20,000 lb. per sq. in.
Crushing strength of cylinders up to	39,000 lb. per sq. in.
Specific gravity	2.4 to 4.5
Expansion for 180 deg. F	1/8 in. in 12.13 to 12.81 lin. ft.

182. Defects or Blemishes in Glass.—The defects to which glass is subject in the process of manufacture are of two general kinds: (1) those due to imperfect polishing and grinding, and (2) those that are contained in the body of the glass itself. In cutting the large sheets into commercial sizes, care is taken to eliminate as far as is practical any defects or blemishes that may be present and to obtain the largest possible percentage of the better grades of the glass.

The principal defects due to grinding and polishing are as follows:

Sand Lash.—This occurs near the edges of the sheet if the grinding block runs off. It is a collection of scratches and is easily detected.

Grey Spot or Short Finish.—This is caused by insufficient grinding or polishing. It has the appearance of a collection of dust and sometimes requires a careful examination to detect.

Block Reeks or Sleeks.—Caused by a coarse particle of rouge working under the polishing block. It is a smooth scratch and shines out sharply in reflected light.

Burned.—A spot where the polishing block was allowed to run dry thereby causing the surface film to start to melt. It has a finely and slightly mottled appearance on the surface but not in color.

The following are the principal defects which may be contained in the body of the glass:

Bubbles and Blisters.—The name describes this defect.

Seed.—Fine bubbles.

Ream.—A defect the cause of which is difficult to determine. It results in a distorted image when looking at an object at an angle.

Waves.—An undulation of the surface. Owing to the method of manufacture, these can not be entirely avoided in cylinder glass.

Stone.—A particle of unfused material embedded in the glass. This is one of the most serious defects to which glass is subject as it makes a point of high local stress and is very likely to cause the glass to crack.

String.—An irregular shining streak made by the passage of a small "stone" during the manufacture of the sheet.

Skim.—Streaks of dense seed with fine bubbles.

Scratches.—Any marking or tearing of the surface appearing as if done by a sharp or rough instrument.

Lines.—Waves which extend continuously across the sheet, so that the reflection from the surface appears as a line or series of lines.

183. American and Foreign Glass.—Practically all glass, now on the market, and used in connection with building, is produced in America and the following data are intended to cover the manufacture, qualities, and sizes of the various domestic glasses in general use only.

184. Grading.—In the manufacture of glass only one product is aimed for and the various grades or qualities are the results of selections made in the effort to separate those sheets which are nearest perfect from those which contain some of the blemishes inherent in the process of manufacture.

In this process of selection and separation, the personal equation enters to a considerable extent, the grade being determined largely by the general appearance of the sheet. Thus a small defect or blemish might be permitted in a large light and be the cause for rejection if occurring in a small light. For this reason small size samples seldom correctly indicate the quality of the glass proposed to be furnished.

It is sometimes very difficult to determine in what grade a particular sheet of glass should belong, and for this reason it is not infrequent that a lower grade than the grade specified is substituted. This is especially true in the case of AA grade.

185. Cylinder or Window Glass.—This is the common commercial "window glass." It is more or less wavy in appearance, usually has a slight bulge, and varies widely in composition and quality.

185*a*. Manufacture.—It is made by blowing the molten glass into a cylindrical shape and then cutting, heating, flattening out, and annealing Formerly all glass of this type was hand made, but during recent years machine methods have been perfected and the hand-made glass has largely been supplanted. The machine-made glass is the usual commercial "window glass."

185*b*. Sizes.—Window glass is made in two principal weights or thicknesses—***single strength and double strength.*** Window glass heavier than double strength is known as ***heavy sheet glass.***

The following is taken from the U. S. Government Master Specification No. 123:

TOLERANCES IN THICKNESS AND AVERAGE WEIGHT OF CLEAR WINDOW GLASS

Classification	Thickness		Number of lights per inch		Average weight, ounces per square foot
	Minimum, inches	Maximum, inches	Minimum	Maximum	
Single strength	0.080	0.100	10.5	12.0	18.5
Double strength	0.111	0.125	8.0	9.0	24.5
26-oz. glass	0.125	0.135	7.5	8.0	26.0
29-oz. glass	0.135	0.148	6.5	7.0	29.0
34-oz. heavy glass	0.150	0.175	6.0	6.5	34.0
39-oz. heavy glass	0.176	0.205	5.0	5.5	39.0

Sizes Obtainable.—The maximum dimensions recommended are

Classification	Width, inches	Length, inches
For single strength	40	50
For double strength	60	80
For heavy sheet	66	90

Tolerance in Thickness.—Thickness of individual sheets shall not vary more than one-half of the total variation allowed for that particular strength of glass, as shown in table above, for sizes up to 50 united inches. For larger sizes, variations in thickness may be equal to the tolerance allowed for that class.

Flatness.—All clear window glass shall be relatively flat. Slight curvature, provided it is regular, will be allowed, but the maximum deformation or bow shall not make an arc higher than 0.5 % of the length of the sheet. Reverse curve or crooked glass is not allowable.

185c. Grades.—Single- and double-strength window glass is marketed in three grades—AA, A and B. The AA quality is especially free from defects, but only about 3% of the total amount of window glass produced is of this grade. The jobbers stocks usually consist of the A and B grades, the A grade containing all glass better than B. The production of glass of the A grade is sufficiently large to meet the general demands for glazing and is suitable for building requirements where a good grade of cylinder glass is wanted. The B grade is suitable for use in mills, factories, the cheapest class of residences, basements of buildings, and work or locations of a similar character.

The following requirements for single- and double-strength glass is taken from the U. S. Government Master Specification No. 123:

(*a*) *A Quality.*—The defects permitted in this quality are faint strings or lines, slight burn, small seeds, small blisters, and light scratches. No light shall contain all of these defects, and those present may not be grouped when in the central area of the sheet. Strings, lines, or burn specks shall not be of such intensity that they are visible when observing the sheet at an angle greater than 30 deg. between the line of sight and the glass. Waves shall not be visible at an angle greater than 20 deg. with the glass. Blisters shall not exceed ¼ in. in length unless they occur near the edge of the sheet.

In general, the central area of the light shall be practically free from defects, and the appearance of the light as a whole shall be such that there is no perceptible interference with the vision so long as one is not looking through the glass at an acute angle.

(*b*) *B Quality.*—This quality admits of the same kind of defects as A quality, but they may be larger, heavier, and more numerous. Occasional scattered blisters not more than ½ in. long may occur over the central area of the sheet. Larger blisters up to 1 in. in length may occur about the bordering areas.

Waves should not be of such intensity that they are visible when observing the sheet at an angle greater than 45 deg. with the glass unless on the border.

Burn spots may be visible when looking directly through the glass, but they must not cause any appreciable depression, and the speckled appearance must not be so great as to interfere with vision when examining the glass in the specified position.

Heavy sheet window glass is produced in *glazing* and *factory-run* grades. The U. S. Government Master Specification requirements for heavy sheet window glass are:

(a) *Glazing Quality.*—The same specifications for selecting provided for A-quality single-strength and double-strength glass shall apply.

(b) *Factory-run Quality.*—This quality is the run of glass as produced by the factory. It may contain glass of very good quality and some glass of very ordinary quality. However, the glass that contains heavy cords, lines, or strings over the entire surface, raised blisters, cap strings, stones, or batch particles causing a rough surface or depression or having its surface covered with heavy burn, wrinkles, deep scratches, or stone shall not be included in this quality.

186. Polished Plate Glass.

186a. Manufacture.—The raw materials from which plate glass is made are virtually the same as used for cylinder glass, but the method of manufacture is entirely different and greater care is taken in the selection and purification of the ingredients.

The various ingredients are melted in a large earthenware pot, are then poured on a flat iron table and a heavy iron roller quickly passed over it, leaving a plate of glass of the required thickness. This plate is then annealed and forms what is known as *rough plate glass.* It is unevenly fire polished on one side and rough on the other. In this form it is sometimes used for vault and floor lights, skylights, etc.

Rough rolled or *half polished plate* is rough plate ground and polished on the smooth or fire polished side only.

Ornamental plate is a figured plate glass made by rolling or rolling and pressing and having the plane surface ground and polished.

For polished plate glass the rough plate is secured to a revolving table and the surface of the glass ground down with fine sand and rollers. After the grinding has been completed the plate is removed to another table where by means of felt blocks and rouge or iron peroxide the surface of the glass is polished.

During the grinding and polishing the rough plate loses from 40 to 50 % in weight and the method of manufacture is such that there is usually a slight variation in the thickness of the finished sheets, especially in the large sizes.

186b. Grading.—While no generally accepted standards have been established to determine the dividing line between the various grades of plate glass, the manufacturer grades and lists his stock as follows: (1) First silvering, (2) second silvering, (3) selected glazing, (4) glazing, (5) second glazing, and (6) skylight.

The *silvering* qualities are as nearly perfect as it is practical to manufacture, and are used for making the best class of mirrors. The *selected glazing* quality is almost free from blemishes and is used for special windows, glazing in high class residences, show cases, and sometimes for mirrors. The *glazing* quality may contain a few small bubbles, fine scratches, etc., not however in sufficient quantity to impair its durability or value for ordinary use. This is the usual commercial grade of polished plate glass used for glazing show windows, sash, doors, etc. The *second* quality glazing permits of more defects than the glazing quality but may be used for unimportant work. The *skylight* quality permits the inclusion of defects that would preclude its use for general glazing purposes.

U. S. Government Master Specification No. 123 gives two grades of plate glass for glazing purposes, *viz.*, *second silvering* and *glazing.*

It is seldom necessary to specify other than "glazing" quality of polished plate glass of the standard thickness for all general glazing purposes, and "silvering" quality of polished plate glass and thickness for all mirrors. French plate glass mirrors, except small hand mirrors, have not been on this market in commercial quantities for a number of years, and if actually required would in all probability have to be specially imported.

186c. Size and Thickness.—The following is taken from the U. S. Government Master Specification No. 123:

Sizes and Thickness.—The standard thicknesses of plate glass shall be 1/8, 3/16, 1/4, 3/8, 1/2, 5/8, 3/4, 1, 1 1/4, and 1 1/2 in. Sheets are available 1/4 in. thick in sizes having a maximum area of 250 sq. ft. Glass of 1/4-in. thickness may be furnished having almost any desired dimension under the following maximums: 120 × 280, 144 × 260, 160 × 240 in. The standard stock thickness for glazing purposes is 1/4 in., but this may vary between 7/32 and 5/16 in., although 1/8- and 3/16-in. glass are carried in stock in the larger cities.

Tolerances in Thickness.—The maximum and minimum thicknesses allowed shall not be more than the given thickness plus or minus one-half the difference between the standard thicknesses, although, for 1/4-in. glass, occasional

plates as thick as 5⁄16 in. are supplied. The general variation in thickness should not be more than 1⁄32 in. for individual lights under 10 sq. ft. in thicknesses up to 1⁄4 in. The variation in lights over 1⁄4 in. in thickness should not exceed one-half the total tolerance for that thickness.

Tolerances in Dimensions.—Variation from dimensions ordered shall not be more than 1⁄32 in. per 1⁄8 in. of thickness.

The 1⁄8 and 3⁄16-in. glass is largely used for residence windows, car sash, leaded glass, and wherever high polish, clear vision, and minimum weight are required. They are manufactured from the same thickness of rough plate as the standard thickness glass and, on account of the additional cost of grinding and the liability of breakage, are more expensive.

Glass thicker than the standard 1⁄4 to 5⁄16 in. is used for such special purposes as counter tops, shelves, port and deck lights on ships, aquariums, etc., and, if thicker than 3⁄8 in. usually has to be specially manufactured.

The standard 1⁄4 to 5⁄16-in. glass is the least difficult to obtain and is the most economical to use, both the thicker and thinner glass being more expensive.

187. Mirrors.

187*a*. Manufacture.—Mirrors are made by silvering one side of a sheet of glass, and not only is a good silvering process necessary, but a glass of the wrong composition may chemically change so as to react on the silvering and ruin the mirror.

187*b*. Glass for Mirrors.—For general use, only the best grade (silvering quality) of polished plate glass should be used, for, after silvering, defects are magnified and accentuated. Cylinder glass is used in the manufacture of cheap mirrors, known as *shock* mirrors, but the image is always more or less distorted and they are suitable for use only as reflectors of light.

187*c*. Silvering.—There are two processes by which mirrors may be made: the *patent-back* process and the *mercury-back* process.

The patent-back process is the method employed almost entirely today. It consists in the precipitation of a film of nitrate of silver on the surface of the glass and protecting this film with shellac and mirror-back paint. This is a slow and expensive method and the larger size mirrors are difficult to set without damaging the backing. The mercury backing is supposed to be permanent and while the patent back is subject to deterioration it should have a life of not less than 10 or 12 yr.

187*d*. Sizes.—The size of a mirror is limited only by the size in which the glass can be made, but extremely large sizes of glass entirely free from blemishes are very difficult to obtain.

188. Rolled or Figured Sheet Glass.—This is a translucent or obscured glass with a pattern or design imprinted on one side. It is largely used in office doors and partitions and wherever obstruction of view and diffusion of light are required. The more broken the surface, the better will the glass obstruct the view; and the flatter the projections, the better for light transmission. There are upward of 50 different patterns manufactured, such as *ribbed*, *Florentine*, *maze*, *cobweb*, *colonial*, etc., and it has largely supplanted the ordinary ground glass on account of its greater cleanliness and better light diffusing qualities.

188*a*. Manufacture.—Figured sheet glass is manufactured by casting the molten glass upon a table on which the design has been cut and then immediately rolling to the required thickness leaving a smooth fire polished upper surface.

188*b*. Sizes and Thicknesses.—The usual commercial thickness is 1⁄8 in. but certain of the designs are also made 3⁄16, 1⁄4 and 3⁄8 in. thick. It is cast in sheets from 24 to 48 in. wide and 8 to 10 ft. long. All the designs, however, are not made in the extremely large sizes or in the heavier weights. A few of the designs, owing to the character of the pattern, are not made thinner than 3⁄16 in.

189. Wire Glass.—Wire glass is a sheet of glass in the body of which is embedded a wire mesh. It is used chiefly on account of its fire retarding qualities, and the fact that, when the glass is cracked, the fragments are held together by the wire makes it especially suitable for skylight glass and similar uses.

189*a*. Manufacture.—There are three methods by which wire glass is manufactured. By the *Shuman* process a sheet of glass is rolled and while still plastic, the wire netting is pressed into the glass and the surface smoothed. By the *Appert* or *Schmertz* process a thin sheet of glass is first rolled and upon this is placed the wire mesh, at the same time pouring and rolling a second sheet on top and embedding the wire. This is sometimes called the *sand-*

wich process. By the *continuous* or *solid* process the wire netting is mechanically crimped and placed on the casting table and the glass poured and rolled over it.

189b. Sizes and Thicknesses.—Wire glass is supplied in but one quality for glazing purposes. It is made polished and in a wide variety of surface finishes which serve to obscure the vision as well as provide a decorative finish and also special patterns for increasing illumination by diffusion or deflection.

Wire glass may be had in the following thicknesses: ⅛, ¼, 5/16, ⅜, ½, and ¾ in. The standard type of wire used has a mesh about 1¼ by ⅞ in. and is not lighter than No. 24 B. & S. gage, except for ⅛ in., in which No. 26 B. & S. gage wire is used. Wire glass can be obtained in sizes up to 60 in. wide and 144 in. long.

Corrugated-wire glass is made in one thickness, which is about 5/16 in. Deep-angle sheets are 2½ in. center to center of corrugations and mesh with corrugated asbestos. Shallow-angle sheets are 2 11/16 in. center to center and mesh with corrugated iron.

189c. Kinds of Wire Glass.—Wire glass is made with the following kinds of surface treatment: Rough, ribbed, figured, semi-polished, and polished. There is no such wire glass as *plain* wire glass and the use of the term leads to confusion as to whether rough or polished glass is intended.

Rough wire glass is the glass just as it comes from the rollers. It is rough on the side next to the casting table and smoothly fire polished on the top surface.

Ribbed wire glass has a corrugated or grooved surface on the casting table side and is smooth on the other side.

Figured wire glass is similar to the above except that it has a figure or design on one side. There are many of these designs from which choice may be made, among the more common of which are Maze, Colonial, Moss, and Romanesque.

Semi-polished or rough-rolled wire glass is ground and polished on one side only. It permits a well-defined vision up to a distance of 5 or 6 ft., and is sometimes used in elevator doors and where perfect transparency is not an essential requirement.

Polished wire glass is rough wire glass after having both sides ground and polished. This glass is sometimes incorrectly referred to as polished plate wire glass. The method of casting the glass in the manufacture of wire glass is different from the method used in making plate glass and does not produce a sheet as free from bubbles as the latter method. While the more perfect sheets of rough wire glass are selected for polishing, the finished product is not supposed to be as free from bubbles and minor blemishes as polished plate glass.

190. Prism Glass.—This glass has horizontal lines of prisms on one face and is smooth on the other. These prisms change the direction of the light and throw it back into the room, thereby materially increasing the general illumination.

The usual forms in which this glass is manufactured are sheet prism, prism plate, prism wire, and prism tile.

Sheet prism glass is made in sizes up to 60 in. wide × 138 in. long; thickness up to 42 in. high, ¼ in., and over 42 in. high, 3/16 in. *Prism plate* glass has the smooth side ground and polished. *Prism wire* glass is designed for use where deflection of the light and fire protection are both required. It is made in sizes up to 42 in. high × 138 in. long and is ⅜ in. thick. If used in sizes etc. conforming to the rules and regulations applying to other wire glass, it is approved by the Fire Underwriters. *Prism tile* are made in 4 and 5-in. squares, are set in hard metal glazing bars, either zinc finish or copper plated, or in solid copper bars; and where required are reinforced with steel bars.

These prisms are made in a large variety of angles and in order to insure their successful use the depth of the room, the height of the ceiling, the source of the light, etc., have to be taken into consideration in selecting the proper angle and method of installation to be used. Some of the manufacturers of prism glass have given the subject of natural illumination considerable study, much of which has been published in booklet and even handbook form to which the users of this material are referred for detailed information.

191. Sidewalk Glass.—Sidewalk lights or vault lights with glass set in reinforced concrete or steel frames are used for lighting basements. The glass lenses are made in various sizes either round or square and as either flat pressed units or drop lenses of single or multiple prisms according to the distribution of light required.

192. Processed Glass.—There are three kinds of processed glass in either plate or window glass—ground glass, chipped-one process, and chipped-two process. The ground glass is made by either sand blasting or acid etching of one surface. The chipped glass is made by applying either one or two coatings of glue to the ground surface.

192a. Chipped Glass.—This surface is produced by coating the glass with hot oil or glue and gradually heating and drying. The drying glue or oil slivers off the glass in various forms, no two flakes being identical, but with a uniform general effect.

A single application and the consequent chipping produces what is known as *single process chipped glass*. If the glass has been previously sand blasted, lines of the original ground surface will remain. If the process is repeated on the *same* side of the glass, all trace of the original surface disappears, the flakes or pattern is finer and the glass is known as *double process chipped glass*.

192b. Ground Glass.—Ground or sand blasted glass has a milky or frosted surface produced by subjecting the sheet to a blast of fine sand.

A ground surface is easily soiled or marked with pencil or chalk and is very difficult to clean. While it obscures vision, it does not give as good light transmission and diffusion as some of the figured patterns of sheet glass. When the ground glass effect is desired, a more satisfactory result may be obtained by the use of either acid ground glass or opal finished glass.

192c. Acid Ground Glass.—This is similar in appearance to the ordinary ground glass, but it has a much finer and more delicate caste, a smoother surface and is more easily cleaned. This surface is produced by treating the glass with hydrofloric acid, rendering it semi-obscure or complete obscure as may be desired.

193. Colored Glass.—Colored glass is produced by introducing various substances into the molten glass and the cost of the glass is largely determined by the cost of the coloring material required to be used. Almost any desired shade or combination of colors may be obtained by the use of opalescent, flashed opal, and cathedral glass.

Figured rolled sheet glass and single and double strength cylinder glass may be obtained in standard solid colors of ruby, green, blue, orange, and violet.

193a. Opal Flashed Glass.—Flashed glass is made by blowing a thin film of colored glass on the surface of a sheet of clear glass. It can be obtained in sheets as large as 37 × 59 in., in either single or double strength, in several degrees of density, and in either white or various tints.

193b. Opalescent or Solid Opal Glass.—This glass is made in both smooth and granite surfaces, in white and various tints, and is cast in sheets about 26 in. wide by 40 to 50 in. long. It is similar in appearance to opal flashed glass, but as the coloring matter is contained in the body of the glass it is considerably more opaque.

193c. Cathedral Glass.—Cathedral glass is made with either a hammered or smooth surface, and in clear and a variety of tints. It is about ⅛ in. thick, is cast in sheets about 30 x 90 in. and is one of the cheapest colored glass on the market. It is largely used for leaded glass work.

193d. Colored Plate or Structural Glass.—White and black structural glass, on account of its nonporous, nonstaining, sanitary and easily cleaned surface, is used for counters, shelves, wainscoting, wall coverings, etc. It is made in sheets up to 60 in. wide, 100 in. long and in the following thicknesses: 3⁄16, 5⁄16, 7⁄16, ½, 9⁄16, ⅝, ¾, 1, 1¼, 1½ in., and in natural, honed, and in ground and polished surfaces.

Elastic cement should always be used for setting this material in order to reduce the liability of cracks caused by the settlement of the building; and, where metallic supports or angles are used, they should be packed and care taken in tightening bolts not to break the glass which is fragile near the edge.

194. Special Glass.—There are kinds of special glass on the market which have been manufactured to meet some specific need, such as actinic glass and glass permitting the passage of ultra-violet rays in light.

The actinic glass is used for windows, roofs, and skylights in warehouses or other buildings containing stocks of goods which are subject to fading in ordinary sunlight.

The glass permitting the passage of ultra-violet rays is used in sanitariums, hospitals, residences, etc., to provide a place where patients may be exposed to these rays.

195. Glazing.—Glazing is sometimes specified under carpentry, sometimes under painting, and sometimes made a separate section. In whatever section of the specifications it is placed it is desirable to have all glass under the one heading, Glass and Glazing.

195a. General Notes.—All rebates in wood sash or doors should be primed before the glass is set, otherwise the wood will absorb the oil from the putty. All glass should be accurately cut to fit the rebates, preferably with a slight play and especially so in connection with metal. Rebates should be of proper size and depth (¼ in. minimum) to receive the glass.

All bending of curved glass is done at the factory and it is necessary to furnish accurate measurements, profiles, etc. All kinds of glass may be bent by placing the flat sheet on a mold formed to the shape required and heating sufficiently to allow the glass to soften and fall to the shape of the mold, after which it is necessary to re-anneal the glass.

195b. Setting Glass.—Glass is secured in place by means of putty or glazing beads or molds. When set in wrought-iron doors, the glass is sometimes bedded on felt or rubber strips. Sash are usually puttied, and beads or molds are usually used (always in first-class work) in connection with doors, glazed partitions, etc. Sash should be glazed flat and putty allowed time to harden before handling.

Plate glass in large lights, such as in store front construction should be supported on pads of felt, leather, lead, oakum, or soft wood blocks, one at each end, and the glazing beads or molds, especially if of metal, should not be drawn too tight.

In setting mirrors care should be taken that not only the backs of the mirrors but also their frames or supports are protected from dampness. If set in small lights, as in French doors, especial care should be taken to have the backs of the rebates all in a true plane, otherwise the image will be distorted. To avoid this possible distortion a large mirror is sometimes used with false muntins on the face. If broken, however, this type of construction is very difficult and expensive to repair. The backs of all molds and false muntins should be painted black to prevent their reflection from showing.

Cylinder or common window glass usually has a slightly bowed surface and should be set with the bowed or convex side out. This not only increases the strength of the glass but tends to lessen the distortion.

Wire glass should be set with the twist of the wire running vertically.

Figured glass in office doors should be set with the smooth side out (toward corridor) to allow for sign painting, and in windows with the rough side out wherever possible as the light transmission is better with the rough side toward the source of the light. This, however, does not necessarily apply to the scientifically designed prism glass.

195c. Putty and Puttying.—Glass in window sash is usually secured in position by means of small triangular pieces of metal—known as *glaziers points*—spaced from 6 to 10 in. apart, and then covered with putty so as to fill the rebate. This is known as *face puttying.*

Bedding is a term used when a thin layer of putty is spread on the rebate of the open sash and the glass pressed in the putty to an even bearing.

Back puttying consists in pointing up or forcing putty into those portions of the joint between the inside face of the glass and the rebate where the glass and the wood have not made absolute contact.

In the best work glass in doors, especially in outside doors, is bedded and back puttied as well as secured with molds, and in sash is bedded, back puttied and face puttied. Stock sash are only face puttied and other sash will not be bedded and back puttied unless specifically called for. Figured glass if set with the rough side to the rebate is not usually bedded or back puttied on account of the difficulty in removing the putty from the ridges and depressions on the glass.

The common commercial putty generally used for setting glass, where no particular make or brand is called for, is frequently of very poor quality. The best putty is made from pure whiting, linseed oil, and about 10 % of white lead paste. The addition of more white lead will cause the putty to dry too hard and to adhere so firmly to the rebate as to make re-glazing very difficult without damaging the muntins.

195d. Metal Store-front Construction.—Plate glass in show windows, store fronts, etc., is usually set in metal sash bars, sills, division bars, etc., the area of the metal or obstruction of view being reduced to a minimum. There are several standard makes of all metal store front construction on the market and detailed descriptions and full size drawings of the different members may be obtained from the manufacturers. The best types secure the glass from the outside by means of a metal locking or clamping member and provide for drainage, ventilation, and illumination if desired.

PAINT, VARNISH, LACQUER, STAINS, AND WATER PAINTS

BY M. Y. SEATON AND GLENN H. PICKARD

Paint, varnish, and lacquer, while often looked at as decorative materials only, should be considered as protective materials as well. At times, in the use of surface coatings, one of these two purposes overshadows the other, dependent upon circumstances. These offices are performed through building up successive thin surface coats or layers of materials that have distinct properties and separate services to perform; and each of these will render this service according as to whether or not it is the requisite material and correctly or incorrectly applied to a proper base. The function of stains is more decorative than protective, being used under paints and varnishes to bring out color or graining.

196. Paint as a Structural Material.—Paints perform one or more important structural functions. As preservatives, they may, if the films are kept intact by occasional renewal, prevent rusting of iron and steel or, by excluding moisture and air, prevent or retard the decay of wood. As reflectors of light, they may increase the usefulness of office, factory, and warehouse spaces and, by their decorative effect, make surroundings more pleasant and make possible the use of materials the aspects of which are unattractive.

197. Evaluation of Paints.—High quality in paint is dependent as much upon physical properties as upon chemical composition and properties if not more so. Chemical analysis can detect conformity or the absence of it with specifications or stated composition; can, to a very appreciable extent, determine the quality of the individual ingredients. Chemical analysis will not give final evaluation, because qualities dependent upon the physical state of chemical compounds and upon certain relations between the ingredients profoundly influence the service-giving qualities of protective coatings.

Physical tests are not standardized, nor are they of universal application. Several systems of accelerated weathering have been announced and are used to a limited extent. The results obtained are not always consistent with themselves or with actual exposures under the conditions of service which is the most reliable means of evaluation. Knowledge of the existing data resulting from many exposures under varied conditions enables one to specify compositions that will meet all normal exposures and many special ones. Such data are available in publications, for instance, as those of the American Society for Testing Materials and the Scientific Section of the American Paint and Varnish Manufacturers' Association.

198. Composition of Paints.—All paints consist of a vehicle, usually an oil or an oil containing varnish which hardens to a rubber-like mass of varying properties due to oxidation by the air; a pigment—that is, finely divided solid—or body of coloring matter in a state of suspension in the vehicle and dispersed throughout and surrounded by hardened vehicle to form the film; and a thinner to bring the mass to proper consistency for application. These must be suited to one another and to the use to which the paint is to be applied.

199. Functions and Properties of Paint Films.—When applied on wood, paint protects by exclusion alone; that is, it keeps away from the underlying surface the destructive forces of the atmosphere, the most important of which are moisture and the oxygen of the air. By preventing contact with them, their effect on the wood decay is prevented. This is accomplished by saturating the wood for an appreciable depth with a water-repellent, oxidized oil and by forming upon the surface a more or less impervious film which greatly lessens the extent of penetration of the wood by the atmosphere and by water deposited upon the paint film.

In the case of steel, the protective forces are exclusion and inhibition of rust formation. The first is accomplished by the film of paint, while the second results from the chemical or electrochemical properties of the pigment. With an inhibitive pigment, rusting is prevented or retarded even though moisture and oxygen penetrate to the metal, while if a non-inhibitive pigment is used, rusting starts at the points where exclusion is not complete and travels along the surface around these, at first, minute entrances.

Typical common inhibitive pigments are red lead, sublimed blue lead, and zinc chromate. The first two are the ones most widely used.

The properties of a newly formed paint film are fundamentally those of a plastic solid possessed in varying degrees of elasticity, distensibility, toughness, hardness, and imperviousness.

These properties, except, in some instances, hardness, are possessed to the greatest extent by the film when it has become thoroughly dried or hardened. From then on, decay gradually diminishes them all with the one exception of hardness, which gradually increases until brittleness or friability results.

Oxidation of the vehicle, of which reaction the actinic rays of light are a powerful catalyst, is the most potent cause of paint failure universally effective on exposed surfaces. It causes, first, a shrinkage of the film which sets up stresses and strains that must be met by the cohesion of the film and the adhesion of it to the surface. As the oxidation proceeds, the film will either crack uniformly over its entire surface with very small areas surrounded by the cracks, or it will crack with relatively wide and long cracks enclosing comparatively large areas of the film. The former type of failure results in chalking, while the other tends toward peeling and scaling or the formation of deep fissures generally extending from top to bottom of the film. Chalking is by far the most desirable form of failure because it presents the more satisfactory surface for repainting.

The properties of paint films as manifested by appearance, character of service rendered, and manner of failure are dependent upon several different influences. Sometimes but one is of importance, while at others a combination of them produces the effect noted.

Among the more prominent of these functions of paint performance are the vehicle used, the chemical and physical properties of the pigments, the presence or absence of the reaction products between pigments and vehicle and their character, the color of the pigment, the ratio of the volumes of pigment and fixed vehicle, the age of the film, the surface over which applied, the atmosphere in which the paint is exposed, and the location of the exposure, particularly with reference to incident light.

If the vehicle is linseed oil, the freshly formed paint film will be elastic and tough. The greater the capacity of the oil to take up oxygen the less cheesy the film will be. If a varnish is employed in part or alone as the vehicle, the film will be hard and tough shortly after its formation. Paints with much varnish or heat-treated oils in them are enamels. Varnishes tend to cause failure by cracking.

Pigments which are chemically inert form no bond between themselves and the vehicle. This tends toward early failure by chalking in whites and tints and at a normal rate in colors. The finer the pigment is ground the more dense and even the film. Coarse pigments shorten the life of paints because they present a relatively rough surface over the high spots of which the vehicle rapidly fails. The reactive pigments are basic and form soaps with the oil and resin acids of the vehicle. By this means there is formed a bond between pigment particles and vehicle which profoundly influences the film. If the soaps are soft and elastic, then results a paint which fails by checking or fine cracking followed by chalking. If the soap is tough and hard and forms a colloid with the rest of the vehicle, a film results which is very cohesive, lacking in elasticity, and which fails by cracking often followed by scaling and peeling. The character of this bond between the pigment and vehicle, and, consequently, that of the paint itself, can be controlled by the selection of the pigment and the proportions used. The lead pigments form the soft, elastic bond, while those containing zinc oxide yield the hard, dense type.

The chemically inert pigments which form no bond fail by chalking in an oil vehicle. With white pigments this happens in a comparatively short time.

Inasmuch as light, coupled with oxidation, which it hastens, is the most powerful unavoidable influence of paint failure, those pigments which absorb the most light protect the vehicle longest and thus prolong the life of the paint. Black gives the most durable paint, other things being equal, and white the least durable, with the shades and tints intermediate. Because glass absorbs the actinic rays, interior paints are more durable than exterior.

Another means of protecting the vehicle and thus prolonging the service afforded by a paint is by increase of the ratio of the volume of the pigment to that of the fixed vehicle. Low-pigment-volume paints fail with relative rapidity, no matter what their composition, while those with a pigment content such that from 30 to 40 % of the volume of the film is occupied by pigment give the maximum service. This fact is a very important and comparatively recent development of protective-coating research. It results because the greater number of pigment particles proportionately absorbs or deflects a greater percentage of incident actinic rays of light.

As the age of a paint film increases, the elasticity and distensibility of it decrease as a result of the hardening of the vehicle. Chalking or incipient cracking begins with progressive hardening resulting from oxidation.

The surface upon which any protective coating is laid influences the service that will be rendered. Rough surfaces expose a greater area for contact than do smooth ones. Greasy or damp surfaces prevent adhesion and contribute to blistering and peeling. Absorbent bodies withdraw vehicle from the wet films and make necessary more coats for complete protection. Uneven absorption is hard to combat. In extreme cases, the porous areas should be touched up to prevent the piling up of too much paint on the non-absorbent areas.

If the atmosphere about the surface carries excessive amounts of moisture, active gases, alkali or acid sprays, or mists, the paint film is damaged. The pigments, as a rule, are stable, except in appreciably acid areas, but the protection vehicles are sufficiently reactive to be affected by these conditions.

Obviously, surfaces located in such a manner that light containing high proportions of the actinic rays strikes them and where the sunlight is effective for longer periods of time will require more frequent painting for proper protection than if the reverse conditions obtained.

200. Pigments.—Paint pigments are divided fundamentally into whites and colors. The whites are subdivided into opaque and transparent or extender pigments. The colors are subdivided into natural earth pigments and chemical. In the chemical class we have the solid colors and lakes, the lakes being organic dyes precipitated on inorganic bases.

200a. White Pigments, Opaque. *Lead Pigments.*—Lead pigments of white color are opaque and chemically active. The one commonly known as white lead is basic carbonate of white lead, while another is basic sulphate. The former is made by the corrosion of metallic lead in one of several ways, while the latter is a fume pigment. Basic carbonate white lead is the only white pigment which can be used alone or with tinting colors ar the pigment. The lead pigments form a bond with the vehicle which causes failure by chalking, because it but slowly loses its elasticity and causes the film to fail by checking, followed by chalking.

Zinc Pigments.—The white zinc pigments are zinc oxide and leaded zincs. Zinc oxide is a practically pure oxide of zinc made from metallic zinc or from an ore which yields pure zinc oxide as a fume by reduction followed by oxidation. The particles of zinc oxide are the finest of all white pigments and second only, perhaps, to some lampblacks in this respect. The leaded zincs are made by the reduction and oxidation of ores which yield a fume product consisting of zinc oxide and basic sulphate of lead in varying proportions. Formed as they are together, they produce paints of different qualities than when zinc oxide and basic sulphate of lead are mixed in the same proportions. Zinc oxide reacts with vehicles to form soaps of a very dense, hard character. They cause lessened adhesion to the surface and also failure by cracking, followed, in many instances, by cracking and scaling or peeling. Zinc oxide forms the products which cause washing when paints containing it are applied and allowed to dry in relatively damp, cold weather.

Lithophone.—Lithopone is a white pigment made by simultaneously precipitating zinc sulphide and barium sulphate by the mixing of soluble salts of each. It is an extremely white pigment, now stable to light and, therefore, valuable for use in exterior as well as interior paints. The hiding power of lithopone is high. Lithopone is inert, forming no bond with the vehicle except as it may contain a small amount of zinc oxide. This causes early chalking unless corrected by accompanying zinc pigment.

Titanium Pigments.—Of recent years, titanium oxide, either alone or in a composite pigment with barium or calcium sulphate, has come into comparatively wide use. Pure titanium oxide possesses the highest hiding power of any white pigment. Its high cost prevents wide usage. As a composite pigment of about 25 % titanium oxide and the balance barium sulphate, sold under the name of titanox, titanium enjoys an increasing consumption. It is an absolutely inert pigment, forming no bond whatever with the vehicle and, therefore, fails early by chalking. Zinc oxide generally accompanies it in paints.

200b. White Pigments, Extenders.—The extender pigments are natural products, the most important ofwhich are barium sulphate, calcium carbonate or whiting, silica, china clay, and magnesium silicate. These pigments are termed extenders because they impart neither color nor opacity to the paint. Intelligently and conscientiously used they are an asset to the paint industry. They form no bond with the vehicle.

200c. Colored Pigments. *Reds.*—There are red pigments both of natural and of chemical origin. Iron oxide is the most important natural red pigment. These oxides vary in their content of iron and in their shade. Some are made by the precipitation of iron salts followed by furnace treatments to develop a red of desired shade. They usually contain calcium sulphate which detracts from their value, especially on metal.

In the chemical class there are many red pigments produced by the precipitation of materials like paranitranilin and toluidine on barium sulphate or other inorganic bases. Red lead is an orange-red pigment. It is the most widely used and the best rust-inhibitive pigment available. Recently, pigments of high true red-lead content have been manufactured which permit of marketing the material as a paste or liquid paint, whereas, previously, such paints were prone to cake or settle badly. The physical state of the material permits of high pigment concentration and, therefore, maximum protection. The efficiency of it is reduced by any admixture except black and blue used to make the color of the paint brown or black.

Yellows.—These occur as natural and chemical pigments. The natural ones are generally hydrated iron oxides mixed with silicious material of which ocher is typical. Others are the chrome yellows and zinc chromate. The latter is used, to a limited extent, as a rust-inhibitive pigment. Both classes of yellow pigments are used, to a great extent, as tinting colors.

Greens.—Greens are, for the most part, chemical pigments. The most important of them are a mixture of Prussian blue and chrome yellow prepared in pulp state. Their greatest use is as tinting colors, though solid greens are fairly prevalent.

Blues.—Blues are chemical pigments used, to the greatest extent, as tinting colors. Prussian and ultramarine blues are the most important. Sublimed blue lead is a fume pigment of a modified basic sulphate of lead base which is an excellent rust inhibitive and, therefore, valuable in metal paints of all kinds.

Browns.—The brown pigments are usually iron oxides containing silica and sometimes much manganese. The umbers are of this latter class. They have much the same properties as do red oxides of iron, save color.

Blacks.—Lampblack, which is a soot pigment made by the burning of oil and carbon black by the burning of gas, are the most important black pigments. They are used as tinting colors or with inert pigments in solid black products. Both are exceedingly fine products. Drop or boneblack is the blackest of all pigments. Graphite is a very important pigment of this class. It is used in large amounts on top coats for ironwork. It makes a paint film which is very impermeable and of high excluding power. Black oxide of iron is a valuable pigment used, to some extent, as a rust inhibitive.

201. Paint Vehicles.

201a. Drying Oils.—Drying and semi-drying oils are the most important paint vehicles. Linseed oil is by far the most widely used. It is used as raw oil, boiled—that is, containing driers in solution which shorten the drying period—bleached oils—that is, those of pale color—and bodied oils, the latter used particularly in enamels. Soy bean and fish oil

are used to some extent. The films that they form are soft and less capable of withstanding abrasion than linseed-oil films. When varnish is used as the vehicle in appreciable amounts, the product is termed an enamel. The so-called high-grade all-oil enamels have as a vehicle heat-bodied linseed oil, with, possibly, additions of relatively small amounts of other oils or varnish.

201b. Thinners.—Volatile oils, called thinners, are used to reduce paint products to brushing consistency. They carry in solution or in a colloidal state the non-volatile portions of the vehicle and any products which result from the reactions between the pigment and the vehicle. For paints, turpentine is used to a very great extent. It has better solvent powers than other materials used in its stead, both for the materials of the paint and for the resins of the wood. By reason of the latter property, it causes better penetration and anchorage of the film to a wooden surface. Petroleum thinners of several distinct distillation ranges are used to a great extent. As previously stated, they are inferior to turpentine in wood priming coats. If properly made—that is, possessing no non-volatile residue and no tendency to darken—they are very satisfactory thinners for many purposes.

201c. Driers.—These are soluble compounds of lead, manganese, cobalt, or mixtures of them present in the vehicle. Their function is to accelerate the absorption of oxygen and consequently the hardening of the drying oil. Their use in excess hastens the final disintegration of the paint film.

202. The Manufacture of Paint.—The manufacture of paint is a comparatively simple operation. It consists of three steps: first, mixing the pigment and the vehicle; second, grinding this mixture to a paste; and, third, thinning the paste to proper consistency for application. The mixing operation is important and practically the same for all types of paint. In grinding to paste form it is essential that the grinding be thorough so that the pigment will be completely wet by the vehicle, and the particles of the pigment will be fine.

Pastes are of varying consistency. The ordinary paste, as represented by white lead in oil, is a stiff paste fairly hard to break up, while another type, termed semi-paste paint, carries a greater proportion of vehicle and is, therefore, more easily broken up. In the thinning of these pastes, volatile solvents and oils are added, a stiff paste requiring more oil than the semi-paste. The ratio of pigment to vehicle and the oil absorption of the pigment will determine the amount of volatile that is necessary to reach proper brushing consistency.

203. Preparation of Paint for Use.—The ready-mixed paints are those that are made at the factories with all essential ingredients present. They are generally designed for finish coats as they come and, therefore, must be modified for application as primer and second coats by the addition of oil or thinner or both. One essential is that a ready-mixed paint shall be thoroughly mixed, because all paints settle. If pigment and vehicle are not in a homogeneous mass when applied, the proportions of the ingredients will vary and may cause trouble.

To bring a semi-paste paint to brushing consistency more oil and thinner must be added. The character of the paste and the service to be rendered controls the amounts of each. The use of semi-paste paint makes it easy to fit the pigment and vehicle proportions to meet service requirements. In breaking up a stiff paste, such as white lead alone, care must be taken to eliminate all of the lumps. Sometimes, a zinc-oxide paste is added to white lead. When this is done, the mixing and thinning procedure is important, and proper sequence of the additions must be adhered to. First, the lead paste should be softened up with only so much oil as is necessary to make it easily stirred. Then the zinc paste is added to the white-lead paste and thoroughly mixed. Tinting colors follow, then drier, and then the balance of oil and thinner. Because of the tendency of paints and pastes to skin over, it is essential to strain them, in almost all cases.

204. Design of Paints.—It is very important that a knowledge of the properties of the materials and the conditions obtaining that influence the service should be possessed by the designer of the paint. Paints for general use must have ingredients of essential qualities and in proper proportions. Many special cases arise, due to the condition of the surface, the atmosphere of exposure, or the character of the service demanded which must be studied and for which coatings must be designed to meet them. Many paint failures are unnecessary because paint has been used incapable of rendering the service demanded.

205. Application of Paints.—The surface must be in proper state to receive the coat. In every case it must be dry, for moisture prevents the adherence of practically all paints on almost

all surfaces. Plaster should be free from "hot spots"—that is, areas containing free lime—for free lime will saponify the vehicle, thus causing disintegration of the paint in extreme cases, and will change the shape of many colors if not completely destroy the color pigment. Steel must be free from grease, from rust, and from adhering scale. Wood must be free from mildew, for paint will not stop the growth of this fungus. If pitchy wood is used, larger amounts of turpentine are required to secure anchorage of the paint film. Mineral spirits will not serve.

The first coat of paint, known as the priming coat, must key to the substance to which it is to be applied, must be unaffected by any substances contained in that surface, and must afford a proper surface upon which to apply the subsequent coats. On steel, the priming coat must inhibit the formation of rust. Priming coats must dry to a hard, though elastic, surface.

After the priming coat, the base or intermediate coats are applied when three or more applications are made. When two-coat work is done, the finish coat goes directly onto the primer. As a rule, three-coat work is more satisfactory than two-coat, though, in some cases, fairly satisfactory service is rendered by two-coat work. The finishing or last coat applied is the surface which receives all the wear. It is, therefore, necessary that it not only give the finished appearance desired but also be able to withstand atmospheric and other conditions of use to the greatest possible extent. The priming coat should be well worked into the surface, brushing both with and across the grain. It should be brushed out thin and cover the entire surface as evenly as possible. All coats should be thoroughly dry before the next one is applied.

Application by dipping and spraying are preferable in some cases. There is a question as to the relative capacity for service of properly brushed and sprayed coats of the same material. Paints should never be applied in very cold weather, particularly in cold, damp weather, because it is prone to cause washing, especially in paints containing appreciable amounts of zinc oxide. Less trouble will result from the application of too thin coats of paint than if they are applied too heavily. If not enough paint has been spread, there will be lack of hiding, which can be secured by additional coats. If heavy coats are applied, they are liable to oxidize on the surface, leaving the underlying portions soft. Such a state frequently causes trouble. Too much paint also piles up the depth of the coating too rapidly and finally necessitates an expensive removal of hard masses and cracked and scaling coats by burning them off or by the use of paint remover.

206. Painting Concrete, Stucco, and Plaster.—Painting these surfaces is one of the most difficult problems encountered. The alkaline materials present must be prevented from acting upon the drying oils which they readily saponify. The surface is porous and tends to absorb the paint before drying can occur. This absorption is frequently uneven, causing dull spots in the finish. It is absolutely essential that plaster be dry before a paint is applied. It is much better if the painting can be done after a period of dry weather because of the tendency of moisture from the atmosphere to condense upon the plastered surface. Painting will not prevent the formation of efflorescence unless the source of moisture infiltration is first found and stopped.

Free lime usually disappears from such surfaces after about 2 years' exposure. Only on rare occasions can such a period of weathering be allowed. It is necessary, therefore, to neutralize as far as possible the free lime in the paint. This is best done by dissolving about 6 lb. of zinc sulphate in warm water and then brushing, spraying, or sponging this solution over the surface. Zinc sulphate converts the line into calcium sulphate while the zinc goes to the form of oxide. After thoroughly drying, priming coats may be applied.

For sizing inside plaster surfaces, good paint containing about 50 % of varnish should be used. Varnish size is sometimes used, but while it stops suction and thereby enables the painter to reduce, possibly, the number of coats required for the finish, it does not properly key to the surface and is itself glossy.

If a ready-mixed flat coater is used, 1 qt. of oil should be mixed to the gallon of paint for the first coat, unless otherwise stated in the manufacturer's directions.

If a ready-mixed paint is used, 1½ pt. of turpentine and 1 pt. of linseed oil to each gallon of paint should be added for priming. To other undercoats 1 pt. of turpentine should be added to each gallon.

If hand-mixed paint is used, the proportions of fixed vehicle and thinner should be adjusted to meet the requirements of the plaster, the more porous the more oil required.

Each coat should be allowed at least 3 days to dry, and no painter should permit himself to be hurried beyond the point of absolute safety in assuring results.

207. Painting Brickwork.—Unglazed brick presents a very absorptive surface for painting. Obviously, it must be thoroughly dry before any application is made. In order to obtain a satisfactory result, it is necessary to prevent the brick from absorbing the oil from the finishing coats of paint before they have had opportunity to dry. This may be accomplished by first applying two coats of raw oil with drier or boiled oil. Care must be taken, however, not to use so much oil that a glossy surface results, else the paint will be applied upon a too soft undercoat. It is, perhaps, better to use long oil paints for this purpose. Occasionally, a special

paint designed with a viscous vehicle can be used. The viscosity reduces the penetration and, therefore, fills the pores of the brick by a bridging. Ample time must be allowed for the paint to dry. Approximately 10 days will be required. When the pores of the brick have been sealed up, ordinary paints such as are used for wood are satisfactory. Old stucco or rough plaster surfaces may be treated as are brick walls.

208. Paints for Interior Walls.—Illumination is so largely influenced by wall color that the painting of factory interiors becomes important entirely aside from any sanitary or decorative advantages gained. Cold-water paints are sometimes used but, except in isolated cases, are undesirable, since they are unsanitary, easily soiled, and eventually flake from the surface. Flat wall paints—that is, paints drying with a full finish—are desirable in residences and office buildings. They contain pigments of high opacity and extender pigments mixed usually with a vehicle of a China-wood oil varnish. If of good quality, they will stand repeated washing without injury. For factories, a gloss paint is preferable, as it is more durable, withstands cleaning better, and reflects more light. Such finishes are termed mill whites. They are akin to enamels. Lithopone is almost invariably the principle pigment used, and the vehicle should be especially prepared so that the paint will not yellow with age or on exposure to industrial gases.

209. Paints for Steel.—As previously stated, steel is protected by exclusion and by the use of a pigment which has inhibitive action upon rust formation. Red lead is the most generally used pigment, and none is better. Sublimed blue lead is an excellent inhibitive pigment and can be used as the only pigment of the paint, because it is satisfactory in finish as well as priming coats. Zinc chromate, black oxide of iron, and a special pigment resembling Portland cement in composition are used to a greater or lesser extent. An inhibitive pigment should always be the pigment in the first coat applied to steel. Some of these pigments produce paints which have little durability unless protected from the weather by superimposed layers. Red lead is typical. A paint of high excluding power and resistance to the atmosphere should be used for finishing coats. Red-iron-oxide paints are popular, and graphite forms a paint particularly effective in these respects. Red lead containing sufficient lampblack and Prussian blue to give it a black color forms a very serviceable black finishing coat. The properties of the second coat may be modified depending upon the use to which the painted steel is to be put.

210. Painting Galvanized Iron, Zinc, and Copper.—Galvanized iron is, on account of the character of its surface, especially when new, a very difficult material to paint because of the lack of adhesion of most films to it. It is particularly essential that galvanized iron be painted only when it is absolutely dry.

Paints used for this purpose should have comparatively low cohesion. That is, zinc oxide in any form is best left out because of the hard film which it makes. The use of varnish or bodied or viscous oils increases the adhesion. In some cases, the application of a mixture of 4 parts of naptha to 1 part of boiled linseed oil upon the metal has been used with good results. If galvanized iron is allowed to weather for a year before painting, ordinary oil paints may be used. If this practice is followed, care must be taken that rust formation has not proceeded far enough to make trouble. The use of a solution of 6 oz. of copper acetate or sulphate to a gallon of water has been found satisfactory. This roughens the surface of the galvanized iron and gives it a blackened appearance.

What has been said regarding galvanized iron applies also to rolled zinc.

The painting of copper presents much the same difficulty, and the same general practice is applicable as in the case of galvanized iron.

211. Varnish.—"Varnish is a liquid not containing suspended matter (pigment) used for decoration or protection and capable of being spread in a thin homogeneous film which will dry to a hard coating." It is roughly classified as spirit varnish and oil varnish, according to the vehicle used. Spirit varnishes contain only resin, shellac, or similar substances, and a volatile solvent, usually alcohol or turpentine; oil varnishes contain, in addition to the resin, etc., a drying oil. The oil varnishes are the more important class and embrace numerous types, such as spar varnish, exterior varnish, interior varnish, floor varnish, rubbing varnish, etc. Based upon the relative amount of gum and oil used in oil varnishes, they are known as short-oil and long-oil varnish.

In short-oil varnishes, hardness, luster, susceptibility to high polish, and quick drying are more essential qualities than durability. They include such varnishes as furniture, rubbing, and polishing varnish. Medium oil varnishes include the usual architectural varnishes. In these, hardness, luster, and a fair degree of durability are the most desirable qualifications. In long-oil varnishes, durability is the principal quality desired, and they are intended primarily for exterior use. The short-oil varnishes are hard; the medium varnishes, moderately hard; and the long-oil varnishes, elastic. By blending, almost any degree of hardness and elasticity may be obtained.

The principal raw materials used in the manufacture of varnish are drying oil (linseed oil and China-wood oil), volatile thinners (turpentine, mineral spirits, and alcohol), metallic dryers (metallic compounds of lead, manganese, and cobalt), and resin (copals, including "fossil" gums, dammar resin, shellac, resin, and ester gum).

Architectural-oil varnishes contain resin or gum in some form as an important constituent. The resin is heated until completely melted, and the previously heated oil is then added. The dryers are added either separately or incorporated in the oil, and the mixture heated until it is judged ready to be cooled, thinned, and stored. Hardness is usually obtained by increasing the amount of resin; and elasticity, by decreasing the resin.

The details of manufacture vary in connection with the different grades and kinds of varnish and among different manufacturers in the making of the same kind and grade of varnish. Oil varnish is not a mere mechanical mixture of the various raw materials. Chemical changes take place in both the oil and the resin; and it is possible by varying the methods of manufacture, to produce varnishes of radically different properties from the same kinds of raw materials.

Flattening or flat-finish varnishes are of special and often complex manufacture and frequently contain wax and a small amount of pigment or aluminum stearate or palmitate. Some, however, are produced by the use of China-wood oil not heated sufficiently to prevent it from drying flat.

The principal spirit varnishes used in connection with building are *dammar varnish* and *shellac varnish*. Dammar varnish is made by treating dammar resin with turpentine, or light mineral oil, usually in the proportion of 5 to 6 lb. of resin to 1 gal. of solvent. The resin is not entirely dissolved, and the commercial varnish shows some turbidity or cloudiness. Shellac varnish is made by dissolving white or orange shellac in alcohol. Either wood or a grain alcohol may be used, but on account of the disagreeable odor and danger of poisoning attending its use, the former is seldom used alone, and the use of grain alcohol is usually made a requirement in connection with the manufacture of shellac varnish. A usual proportion for a rather heavy body varnish is 5 lb. of shellac to the gallon of alcohol. This may be thinned to whatever consistency is required in connection with its intended use.

Shellac varnish finds a large use as an undercoating or first coat in connection with varnish and wax finish. Applied in a thin coat it is easily rubbed with steel wool to a dull, smooth surface. It should not be used in connection with exterior work as it has poor resistance to atmospheric conditions.

Shellac, either orange or white, is sometimes used for a finish alone. It gives a very pleasing finish without much luster but requires more coats than oil varnish, is easily worn down, injured, or defaced, and turns permanently white from contact with water.

Architectural varnishes are designed especially for use in the decoration and protection of the exterior and interior woodwork of buildings.

Exterior varnishes have, as a prime requisite, ability to resist exposure. They should be elastic and should resist abrasion, moisture, light and heat, or sun and cold. Spar varnishes were originally designed to protect the spars of ships, but the term is now sometimes applied to a class of tough, elastic interior varnishes as well as a varnish for exterior use. Spar varnish should dry slowly, should have a moderate luster, remain elastic, and be resistent to water.

Marine varnishes are designed to resist salt or fresh water and marine atmosphere.

Coach varnish was originally a high-gloss varnish for finishing carriages, railway coaches, etc., and the term No. 1 coach indicated the best quality. At the present time, No. 1 coach varnish has no definite meaning.

Interior varnishes for general interior finish should be of fair body, moderately rapid in drying, fairly light in color, of moderate hardness, unaffected by occasional moisture, and of permanent luster. The best grades will not turn white on exposure to water. They are not expected to possess the same resistance as can be obtained in exterior varnish. Varied and diverse effects and surfaces are required of them, and the choice of the interior varnish to use largely depends on the particular surface finish desired.

Hard oil finish was originally a finish obtained by rubbing the wood with a number of successive coats of linseed oil. As applied to varnish, the term today is meaningless and does not denote quality, many manufacturers listing a cheap grade of varnish as hard oil finish.

Rubbing varnish is a varnish capable of being abraded with pumice stone and polished. It must be hard, comparatively brittle, must not soften with heat generated by friction nor be affected by the water or oil used in the process, and must be capable of receiving a high polish.

Polishing varnish is similar to rubbing varnish but is capable of receiving and retaining a high polish.

Flat varnish dries to a dull or semi-gloss finish and is used primarily to get the effect of rubbed work at considerably less expense. Ordinarily, interior varnish may be flattened by an addition of turpentine and wax, but the life of the finish is thereby materially lessened. Many of the ready-prepared flat finishes contain wax and should be used with the fact borne in mind that wax is the only material with which they can be refinished, neither varnish nor paint adhering to a waxed surface.

Floor varnish should be elastic, should dry overnight, and should be ready for use in 48 hours. It should be tough and resistant to shock or abrasion and not affected by moderate contact with moisture. Shellac is sometimes used as a floor varnish, but it is brittle, turns white on contact with water, and has poor wearing qualities.

Tests for Varnish.—The testing of oil varnishes by analysis is not a satisfactory way in which to judge quality. The present methods of analysis are not adequate to determine the relative amounts of the different resins or to

separate the drying oils. Moreover, the method of manufacture is, to a large extent, responsible for the quality of different varnishes even though composed of the same raw materials. Recently, much work has been done upon the evaluation of varnishes by physical tests. These are described in the specifications of the Federal Specification Board for the various types of varnishes. The methods for testing water-resisting spar varnish are described in Circular No. 103 of the Bureau of Standards and of interior varnish in Circular No. 117 of the Bureau of Standards. These methods, when employed by one familiar with protective coatings, give valuable information as to the service-giving qualities of the material under test.

212. Lacquer.—Recently, lacquers—that is, protective coatings containing appreciable amounts of nitrocellulose—have assumed great importance in the protective coating field. Their use as materials of engineering is as yet somewhat limited, though they are applied for the finish of interior surfaces such as woodwork and walls of hotels and office buildings.

They are composed of four main ingredients—nitrocellulose, which gives them toughness, hardness, and resistance to abrasion; gums, which give them increased adherence, greater luster, and make them more brittle; plasticisers, which are non-volatile liquid materials which increase the elasticity and plasticity of the coat; and volatile solvents, which are divided into nitrocellulose solvents and gum solvents or diluents. The great advantage of these materials compared with the older finishes is in the speed with which work can be completed with them.

213. Stains.—The function of wood stains is to change or modify the color of the wood and to bring out the grain and texture of it. They are known as oil stains, varnish stains, water or acid stains, spirit stains, and chemical stains, dependent upon the vehicle employed.

213a. Oil and Varnish Stains.—An oil stain is one in which the binder is entirely oil. It is reduced in consistency by the employment of various solvents. A varnish stain is one in which varnish is used instead of oil alone. The selection of the solvent for any stain is important because upon it depends the penetration of the stain into the wood. Further, some solvents affect the dyes that may be used to impart color. In this type of stain the color may be acquired through the use of soluble aniline dyes or by pigments of high tinctorial power of which so little need be used that the finish appears transparent though colored.

Because of their ease of application and cheapness, the aniline stains are supplanting the pigment stains. These stains are easy to apply and do not raise the grain of the wood and, consequently, are largely used upon resinous wood such as yellow pine and for the staining of exterior woodwork. They are applied with a brush. It is well to wipe them off to even up the degree of staining and to prevent the obscuring of the grain. In staining such wood as yellow pine, it is well to apply a thin coat of linseed oil and about 10 % of turpentine before staining, because in woods of this class there is a marked difference between the absorption of the heart or harder portions and that of the sap or softer portions of the wood. Consequently, if the stain if applied without previous treatment of the wood there will be too much contrast between the hard and soft portions. The coat of oil tends to equalize absorption of these surfaces. For staining exterior woodwork such as half-timber work, exposed rafters, and so forth, pigment stains are to be preferred because of their greater permanency.

213b. Water and Spirit Stains.—These stains are solutions of dyes, one in water and the other in volatile solvents like benzol, alcohol, or acetone. Because of the lack of any binder they are prone to fade. Occasionally, a mild acid is added to prevent this tendency. They are clear, penetrate deeply, and do not obscure the grain of the wood.

Water stains give the most satisfactory results in bringing out the natural beauty of the wood but have a tendency to raise the grain. In order to correct this, open-grain woods, such as oak, should be first sponged with water, allowed to dry, and then sandpapered The stain may then be applied without further raising of the grain. If sandpapering follows the application of the stain, too much of the stain will be removed and the surface will be dulled somewhat. Water stains are very satisfactory for use upon wood over which lacquer is to be applied. Lacquer is prone to cause the bleeding of stains because of the solvent power of the volatile portions.

213c. Chemical Stains.—These change the color of the wood through chemical action and not through coloring matter contained in a vehicle. They are adapted for use only in connection with woods such as oak, chestnut, and ash and are composed of various chemicals, usually dissolved in water. The fundamental principle is a reaction between these chemicals and some of the constituents of the wood, such, for instance, as tannin.

Among the more commonly used materials are iron salts, which produce various shades of brown; potassium and sodium bichromate, producing various shades of brown and red; copperas, together with zinc sulphate, producing green and various weathered effects; potassium permanganate, producing a soft, silvery gray effect; and numerous others. Chemical stains should not be used by other than experienced painters. As a finish over these stains, varnish or wax can be used.

214. Fillers.—Fillers are finished used to fill the pores of open-grain woods. They consist of a sharp-grained pigment such as silica, with a proper binder. They are sometimes colored by the use of pigments. They are sold as paste and liquid fillers.

Paste fillers are used upon open-grained wood such as chestnut and oak. The vehicle is generally a special type of varnish, or it may be an oil. The paste is thinned with turpentine or benzol, brushed onto the surface, and wiped off after it has set but before it has hardened. Wiping off should be carefully done across the grain so as to remove only the filler upon the surface and not from the grain.

Liquid fillers are of the same general composition but contain a varnish as a vehicle. They frequently are applied as a varnish and are allowed to remain without rubbing off. They have a tendency to discolor the wood and occasionally do not dry out entirely. They are used for cheapness rather than quality and are generally considered inferior to paste fillers.

215. Cold-water Paints.—Under this heading come whitewash, exterior cold-water paints, and calcimines. The last mentioned are purchased in the dry state all ready to add water to, or else the ingredients themselves are purchased and mixed on the job. Calcimines are composed of a white or tinted pigment, generally whiting and clay together with a water-soluble binder such as glue or casein. They have high hiding power because there is no vehicle surrounding the pigment.

The Bureau of Lighthouses, Department of Commerce, Washington, D.C., issues a document which describes what is generally known as Government Formulas for Whitewash. A verbatim transcript is as follows:

The following formula for whitewashing has been found by experience to answer on wood, brick, and stone, nearly as well as oil paint, and is much cheaper: Slake ½ bu. of unslaked lime with boiling water, keeping it covered during the process. Strain it and add a peck of salt dissolved in warm water, 2 lb. of ground rice put in boiling water and boiled to a thin paste, ½ lb. of powdered Spanish whiting, and 1 lb. of clear glue dissolved in warm water; mix these well together and let the mixture stand for several days. Keep the wash thus prepared in a kettle or portable furnace, and when used put it on as hot as possible, with painters or whitewash brushes.

The following simpler formula for mixing whitewash, when properly made and put on, gives a white that does not easily wash or rub off, *viz.*: To 10 parts of best freshly slaked lime add 1 part of best hydraulic cement; mix well with salt water and apply quite thin.

In Farmers' Bulletin No. 474, entitled "The Use of Paint on the Farm" and obtainable from the Superintendent of Documents, Washington, D. C., will be found this and other formulas for whitewash, including those to which color is added for tinting purposes.

216. Standard Definitions of Terms Relating to Paint Specifications.—This is the title of a series of definitions adopted by the American Society for Testing Materials and issued under the Serial Designation D 16-15. Architects and other specifiers, and all users of paint and allied products, should familiarize themselves with the terms and definitions in this document, which relate to various materials, processes, and methods of application. This, together with all other documents of the American Society for Testing Materials, is distributed to members and may be obtained by others for a nominal sum from the secretary at the Engineers' Club, 1319 Spruce St., Philadelphia, Pa.

The Paint Manufacturers Association of the United States, in 1916, also adopted definitions and nomenclature to replace manufacturers' titles or trade names in common use. These are consistent with the above-mentioned standard definitions and are contained in Circular No. 42 obtainable from the secretary at the Bourse Building, Philadelphia.

217. Standard Formulas, Specifications, and Tests.—There are numerous sets of specifications and tests covering the materials employed in the manufacture of protective coatings. Reference to the indices of the American Society for Testing Materials publications, of the Circulars of the Bureau of Standards prepared by the Federal Specification Board covering paint materials, and of the specifications of the British Engineering Standards Association available by addressing this association at 28 Victoria St., London, S. W. 1, England, will disclose a long list of specifications helpful in specifying, designing, and studying from various angles the engineering materials which have been under discussion in this chapter.

BUILDING AND SHEATHING PAPERS AND INSULATING MATERIALS

By D. Knickerbacker Boyd

218. Uses.—In wood-frame buildings, whether covered with clapboards, shingles, or stucco, it is almost always desirable to provide against heat, cold, and dampness. This is the primary use of every kind of insulating material, although the necessity for soundproofing certain rooms or sections of a structure may also require the use of these materials.

(*a*) *Walls.*—For use on side walls against the sheathing, the paper should be permanent, impenetrable to air and water, and tough enough to be handled without tearing. Such paper should be proof against vermin and should not have a strong lasting odor. There are many types meeting these requirements, and the one most appropriate should be selected from samples which will be furnished by the manufacturers. The felt should be lapped toward the ground and well nailed.

(*b*) *Roofs.*—Under slate, tile, asbestos shingles, and metal, "roofing paper" is usually employed to provide a cushion for the roofing materials, insulation against heat and cold, and as a protection to the building until the finished roof is laid. The "paper" bears little relation to the water-tight qualities of the roof, since every nail used in fastening the material is driven through the "paper."

Although the term "roofing paper" is applied indiscriminately to the materials used under roof coverings, the proper description is "asphalt-saturated rag felt." There are many other products on the market for this purpose, but it is economy to use only the best.

Under slate, 14-lb. felt is recommended; the heavier weights of 20, 30, or 40 lb. may well be used where the appropriation allows. On graduated slate roofs, the 30-lb. weight is commonly used when the slates are ¾ in. or less in thickness, and the 50-lb for slate 1 in. or more. In some localities, two layers of felt, the first 30 and the second 12 or 14 lb., are used under heavy slates.

The felt should be laid in horizontal layers with the joints lapped toward the eaves and at the ends. A lap of at least 3 in. should be used, and the edges should be well secured to the surface over which it is laid. A lap of not less than 2 in. should be used over the metal lining of valleys and gutters. If metal other than copper is used as a lining, the felt should be omitted in the valleys. Extend the felt over all hips and ridges at least 12 in. to form a double thickness.

219. Types of Papers.—Because of their interchangeability for different uses, it is difficult to classify the various types of papers and felts. Generally speaking, however, the following will be found to apply. Before deciding upon the type, the architect should consult the data of the manufacturers to be sure that the type he is specifying is the one he wishes to have used in any particular location.

219*a*. Building Papers.—The most common covering or insulating materials are known as "building papers." They are resin-sized paper, usually red or buff in color but sometimes black, put up in rolls usually 36 in. wide, carrying 500 sq. ft. to the roll and weighing from 18 to 50 lb. Ordinarily, they are not waterproof and are used only in the most inexpensive work, such as wall sheathing or between floors where they tend to keep out dust and wind and are also some protection against heat and cold. They are likewise often used for temporary covering and protection of floors or finished work during the erection of buildings.

219*b*. Sheathing Papers.—Sheathing papers are of various kinds. The most common are made of heavy paper or rope stock saturated with a coal-tar product. They are waterproof, afford protection against heat and cold, as well, and have all the other qualities of other building papers. There is some objection to them on account of their odor, but it is claimed that this makes them the more vermin proof and that the odor disappears after a short time.

Sheathing papers are also sometimes called "insulating papers." They are usually 36 in. wide, and the rolls contain 500 sq. ft., weighing from 19 to 50 lb. per roll.

Parchment papers are sometimes used. These are odorless and have a smooth surface, are semi-transparent, and are water-, air, and vermin proof.

Another form of sheathing paper is made of asbestos and is quite desirable on account of its fireproof qualities as well as on account of its being vermin proof and odorless. Such papers vary in weight and thickness from very thin papers weighing only 4 lb. to those 100 sq. ft. in width and ⅛ in. in thickness. The 1/16-, 3/32-, and ⅛-in. thicknesses are used only where fireproofing is specially required, as around flues, chimneys, heat pipes, etc.

Sheathing papers are used, in general, for the better class of building as a protection on frame walls. While the other forms of protection which will be described are, in general, for the same purpose, each kind is particularly designed for a special form of protection.

219c. Felt Papers.—Ordinary felt papers are mostly used for lining floors to render them more soundproof. Some few are made fireproof by means of chemicals, and in some cases an asphalt center is put in to make them waterproof. Felt papers are especially valuable as a deadening material. They are usually quite thick, and the better qualities are soft and pliable so as to form a cushion which aids in the interruption and breaking of sound waves.

Saturated felts are also used under slate, tile, or metal roofing. They are made by saturating ordinary felt with a coal-tar product. A dry-saturated tarred felt is made by running the material through heavy rollers or cylinders to give a hard, smooth surface. This can be easily handled, and the surface enables the roofer to lay out his slate courses on the paper with chalk lines.

Asbestos building felts are mostly used where fireproofing qualities are specially desired but also offer protection against vermin and have sound-deadening qualities.

The so-called "slater's felt" includes many types of materials but cannot generally be recommended for use under slate and other roofing materials.

Asphalt felt and tarred felt are furnished in various weights. The more commonly used range from 12 to 20 lb. per 100 sq. ft. and come in rolls containing from 150 to 500 sq. ft.

220. Insulators and Quilts.—Numerous special types of insulating quilts combine the qualities of thermal insulation and deadening as well as being vermin and air proof. One of the best known is made of thick layers of eelgrass compressed in such a manner as to make a cushion full of air spaces, lined on either side with asbestos. The grass possesses certain qualities which makes it particularly repellant toward rats and vermin.

Another form of such insulator is made of thoroughly cleaned cattle hair, chemically treated and stitched between two layers of asbestos. Still another consists of mineral wool, compressed and lined with asbestos. A mineral-wool insulator can also be secured with lining of building paper. Other types made in the form of blankets, *i.e.*, two layers of paper with wood or flax fibers between, are also on the market. A heat-insulating quilt is manufactured especially for use in keeping out cold, consisting of unbleached linen threads, chemically treated and lined with waterproof or asbestos paper on either side, as required. Other forms of sheathing are made consisting of sound-deadening materials compressed and put together in board form, but these are somewhat more expensive than the rolls.

Nearly all the types of quilts or blankets come in different sizes. In general, however, the roll is used, the widths varying from 16½ to 60 in. The roll usually contains 250 sq. ft. the weight running from 35 to 50 lb. Other types of quilts are furnished packed flat in standard lengths of 8, 9, and 10 ft.

221. Mineral Wool.—Mineral wool is one form of insulation of walls and particularly of overhanging floors which is often used. This insulator is loose, fibrous material manufactured from either slag or asbestos rock and resembling wool in appearance. It is sold in such form that it can be securely placed in the spaces provided.

In overhanging floors, the most common method is to put a false floor about 2 in. above the bottom of the joists and then put on about 2 in. of mineral wool, compress same, and cover with 2 in. of cement or lime mortar to hold it in position. Mineral wool is especially good as an insulator to keep out heat, as in the walls of a cold room.

It should be mentioned that mineral wool, if improperly packed, settles and disintegrates. It must be carefully placed in position and compressed in such manner as to be held in place, or its insulating, sound-proofing qualities will not be retained.

222. Insulation Boards.—During the past 10 yr., there have been extensive developments in the field of insulating materials. There are now on the market several types of fabricated boards for this purpose. Some of these are manufactured from finely shedded fibers of wood, sugar cane, licorice roots, and other materials, closely compacted, rolled, and otherwise treated to furnish a strong board often used in place of wood sheathing and, at the same time, providing desired insulation. Some of these boards are in such forms that, if used on the inside of the wall, they may be plastered upon directly or may be decorated without the application of plaster.

Such boards are furnished in standard sizes and thicknesses, and data regarding these should be secured from the manufacturers. The usual thickness is ⁷⁄₁₆ in, the width 4 ft. scant.

Mention must also be made here of the several types of corkboard used for insulation purposes. This board is composed of granulated cork pressed in molds to standard-sized slabs. While more expensive than some other types of insulation, many advantages are claimed for its use.

223. Other Insulating Materials.—Under other chapters, reference is made to types of insulation made of gypsum, asbestos, and other materials.

BUILDING HARDWARE

By D. Knickerbacker Boyd

The name hardware applies to such an innumerable array of commodities in everyday use that to distinguish the "line" manufactured for use in buildings, the term *building hardware* is employed.

This designates the locks, hinges, pulls, checks, etc., for doors; the lifts, fasteners, pulleys, chain or cord, weights, etc., for windows; the catches, turns, drawer pulls, etc., for dressers; and the various articles suitable for casements, transoms, and other openings in buildings. It is customary in trade circles and among architects and builders to make a distinction between *rough hardware*, such as chain, cord, weights, door hangers, outside shutter and blind hardware, wire screens, etc., and *finishing hardware*, which, as the name implies, includes items. such as locks, knobs, bolts, lifts, transom openers, etc., applied to finished work.

224. Rough Hardware.—Sash cord for windows is made of several different materials and sizes and the same is true of sash chain. The latter can be obtained in steel (plain or coppered), in copper, and in bronze. Sash weights are made of iron or lead. Iron weights are those regularly furnished and are either round or square. Lead weights are used only where sash, when glazed, are unusually heavy or where pulley boxes are too small to permit proper-sized iron weights.

For shutters, various standard lines of hinges and bolts are commonly used, the type varying in accordance with the mill details and wall construction.

Door hangers cover a broad line of manufacture and are made in forms suitable for all styles of sliding doors for both inside and outside use. Headroom above the finished opening must be provided for the type of track, hangers, and brackets used.

225. Finishing Hardware.

225a. Material.—Bronze, brass, bronze-metal, and iron and white metal are the materials most commonly used. These are furnished either in cast or wrought metal. Cast goods are the heavier, more expensive, and in most cases preferable.

While the majority of finishing hardware items are made both cast and wrought, there are certain of them which it is impracticable to produce by both methods. For instance, most of the parts of transom adjusters are of wrought material, while transom centers are all cast. These may also be malleablized when cast in iron.

Cast goods are produced by pouring molten metal into molds, while nearly all wrought goods are stamped from metal sheets by dies.

225b. Color or Finish.—In bronze and brass, the regular product has a highly polished surface, termed a "finish;" other finishes largely used when a high polish is not desired are termed "dull bronze" or "brushed brass." The principal finishes, previous to 1924, were oxidized copper, oxidized brass, oxidized silver, statuary bronze, and nickel and gold plate—each one of which was made in light, medium, and dark shades and with various surface effects too numerous to mention. In 1924, they were limited to 25 standard and 4 special finishes (see Art. 225c).

In specifying finishing hardware it is necessary, if solid metal is desired or required, to prefix the word "solid" before the metal intended,—as solid brass, solid bronze, or other solid non-ferrous metal—except in the case of bronze metal, which is an alloy. Through long usage and trade custom the mere words brass, bronze, etc., unaccompanied by the word solid are taken to mean the finish which in such cases is plated on iron or steel as the case may be.

On iron and steel goods, the finishes commonly applied are: Japanned, lacquered, bronze, brass or nickel plate, oxidized copper, and white metal. The last is always furnished polished and has the appearance of nickel.

225c. General Types.—Some years ago, the Federal Specifications Board undertook the preparation of specifications for builder's hardware, and out of this grew the simplification which has since taken place. The manufacturer's group met for the first time in November, 1922, and the work of standardization was delegated to three subcommittees. Fifty representatives of builder's hardware interests, manufacturers, distributers, and consumers met in May, 1924, at the Department of Commerce, in Washington, D.C., to consider and adopt the recom-

mendations of the various subcommittees. Upon presentation, the entire report received a unanimous vote of approval, and adoption was recorded. These standards have been published as Simplified Practice Recommendation No. 18, Builders Hardware, and copies may be secured at 10 cts. each from the Superintendent of Documents, Government Printing Office, Washington, D. C. They consist of 56 pages, including index, and should be in the hands of all specifiers and users of hardware not only because of the standards (not illustrated) which they set forth and the listings of former types which have been eliminated but also because they give a comprehensive survey of hardware items and requirements which should be considered in connection with buildings.

225d. Details to Which Standard Hardware Can Be Applied.—In 1917, several large hardware manufacturing concerns associated themselves in the issuance of a book with the title given to this paragraph. This should be used by all those making details for woodwork as "the information given covers the minimum requirements for hardware for the various types of doors and windows that have become standard in the class of work in which they are used. It is not intended to suggest any architectural or constructional design, the sole purpose being to fix required dimensions." Some of these details are also used to illustrate this section.

226. Locks.—Locks are made either *rim* or *mortise*. Rim locks are attached to the surface. Mortise locks are set in the door. Both types are subdivided into two groups—*bit-keyed locks* and *cylinder locks*. Bit-keyed locks, which are operated by keys with lobes on long shanks, may be one, two, three, or five tumbler- the greater the number of tumblers the wider the variety of key changes. Cylinder locks which are operated by flat keys with a serrated edge are all furnished with practically similar key mechanism, which permits the use of a single key for the operation of a front door lock, a rear door night latch, a desk lock, a trunk lock, or a padlock, and so on through the entire line. No two cylinder locks are made with same change key unless so ordered.

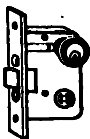


Fig. 84.—Cylinder mortise lock.

Many locks can be furnished *master keyed*—that is, a given lock having 100 or more different changes of key can be so constructed that a master key will operate all of the locks, no two of which are controlled by the same change key. In the best grade of bit-keyed locks, as used on hotels or office buildings, it is possible to furnish all locks on a floor with a different change of key, a separate master key for all locks on the floor and a grand master key for the entire building. With locks of the cylinder type, this same feature is capable of a very considerable extension.

Rim and mortise locks are made in form and function to suit all types and kinds of doors. It is unnecessary to make extended mention of rim locks, aside from referring to night latches and cylinder types, as their use is largely confined to interior passage doors in the cheaper class of small houses, or unimportant doors in basements. Simplified Practice Recommendation No. 18 limits master keying of cylinder locks to standard size cylinders.

Night latches, both bit keyed and cylinder types, are made reversible or suitable for doors swinging in to right or left. When used on doors swinging out they must be made *reverse bevel*. Cases of locks are furnished Japanned, bronze plated, or oxidized copper.

Mortise locks are made either flat or rabbeted front. If rabbeted, the regular size of rabbet is ½ in., small locks for thin French windows being made suitable for ⅜-in. rabbet. If other sizes of rabbet are detailed, the lock faces will have to be especially made, entailing additional expense and possible delays.

The distance from face of lock to center of knob or key hole is called the "backset." The backset of ordinary size locks varies from 2½ to 3 in., but 2¾ in. is generally used (Fig. 84). Regular and special backsets for mortise locks and latches should be confined to 1, 1½, 2, 2½, 2¾, 3, or 3¼ in.; the purpose being to eliminate such special and irregular backsets as 1¼, 1¾, and 2¼ in. as well as other intermediate and larger dimensions (see Art. 225a). Locks with special backsets are obtainable as special items, when French windows, and frequently passage doors, are made with stiles so narrow that standard locks cannot be used.

Flat-faced locks are usually made reversible. Flat-faced locks with bevelled faces and all rabbeted locks are "handed" for either right or left doors (see Fig. 95, p. 1076). Faces of heavy doors must be bevelled to permit the door at closing point to swing free and fit snugly. Lock faces must be bevelled to fit door. Two standard bevels exist, but that most frequently used is ⅛ in. in 2 in.

The grade of many series of locks depends on number of tumblers and character of springs. The number of differing change keys to any one lock is determined in part by the number of tumblers and to the precision of their mechanism. Consequently, all three tumbler locks do not permit of an equal number of change keys. In fact, the variation is very great.

The spring employed in lock construction may be of the simplest flat wire variety—one such spring controlling latch and knob action—or a combination of fine phosphor bronze springs, one set controlling latch and another set the knob or lever handle. It is customary therefore to differentiate between a common spring lock as first indicated and an easy spring lock as last mentioned. An auxiliary spring on hub of lock is a feature added to easy spring locks when lever handles instead of knobs are employed.

With all cylinder locks, the cylinders vary in length to suit the various thicknesses of doors. Mortise cylinder locks of standard type cannot be used on doors less than $1\frac{3}{8}$ in. in thickness, though thin locks are especially made.

Inside door locks or passage door locks vary in size and quality from a 3-in. 1-tumbler lock to a 6-in. 5-tumbler lock in bit keyed series, and through a wide range of size and function in cylinder locks. Locks having special functions are made for office buildings, etc. In addition, locks especially adapted for closets, cupboards, French windows, hinged sash, etc., are procurable in a variety of sizes to suit th working conditions.

Knob locks are constructed with a latch operated by a know and a bolt operated by a key. Communicating locks have regular latch and either one or two bolts operated by thumb knobs. Those with one bolt are designed for use on doors to bath rooms, the two bolt lock on doors between rooms. The latest type includes a key action that prevents operation of bolts until key action is reversed.

Hotel locks are similar to knob locks but are made with two bolts, one operated on inside only by key, and other on outside only by key.

Office door locks, usually of cylinder type, consist of a latch only that is so controlled by the stops in face of lock that outside knob can be operative or inoperative. In the latter case entrance is obtained by key. Exit from rooms always possible as inside knob is at all times operative. When outside knob is inoperative, the door automatically locks on closing.

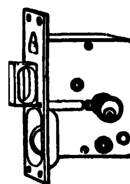


Fig. 85.—Cylinder mortise lock for sliding door.

Locks for institutional use are functioned to accommodate particular needs as well as general conditions.

Front door locks for residence work are in effect a knob lock having the added feature of stop work in face to control outside knob. Key on outside operates both latch and bol' On the inside knob is always operative and both controlled by a thumb knob.

Store door locks are a development of the old style lifting latches and mortise locks. The latch is incorporated in a plate and pull called for the sake of brevity, a handle. Two handles with the lock constitute a set. The locks are made in two main varieties, one with a latch operated by thumb piece of each handle and a bolt operated by a key from either side, the other similar with the added feature of *stop* in face controlling outside thumb piece.

Sliding doors, though now used infrequently in many localities, are provided with a hook or split bolt operated by key from either side, and provided with a pull in face of lock, employed in pulling out, or shutting, the door. This pull remains within case of lock except when forced outward by a stop. The face is made in flat and astragal shape.

Dead locks have a bolt only and may be operated from one side only or both sides by key. A *dead bolt* is similar to a dead lock but bolt is operated from one side only by a turn knob.

A special type of lock and knob combination is manufactured which has the key-way and tumblers placed in the knob and which is completely assembled and attached to the door as a unit.

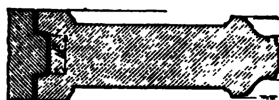


Fig. 86.—Double sliding do with flat astrabal meeting stiles. The stile as shown is suitable for lock with standard backset.

Knobs, lever handles, and escutcheon plates for locks are made with both plain and ornamental surfaces—also in differing sizes and shapes. Round knobs for interior doors are usually $2\frac{1}{4}$ in. in diameter and for exterior entrance doors $2\frac{1}{2}$ in., in diameter. For special purposes they are also made in $1\frac{3}{4}$, 2, and 3-in. diameters. Knobs are coupled by means of spindles either $\frac{5}{16}$ or $\frac{3}{8}$ in. square. Knobs and lever handles are attached to spindles by several methods.

For all locks having a stop in face, a split or swivel spindle is provided for the knob. This form has a joint at the center permitting operation of knob on one side when opposite side is made fast.

Auxiliary springs are frequently used in connection with lever handles to keep them in a normal position. This spring may be incorporated in lock or attached independently of lock. Lever handles of ornamental design are often necessarily "handed" for right or left doors.

An escutcheon may be either a combined rose and escutcheon or an escutcheon plate. The former is made of sufficient length to permit attachment screws to enter wood above and below case of lock and serves both as a rose for the knob and key plate for lock. When knobs are used with roses only, separate plate escutcheons are provided for the key hole. On thin wood doors $1\frac{1}{8}$ in. or less, combined rose and escutcheon should be used as the mortise for lock leaves insufficient wood for secure attachment of key plate.

Glass is now frequently used in the construction of knobs and lever handles and furnished in many different designs, either pressed or cut. The sizes recommended are $1\frac{3}{4}$ and $2\frac{1}{4}$ in.

227. Butts or Hinges.—These articles, the names of which are constantly used interchangeably, are spoken of in the trade by pairs—thus: one butt or hinge is "one-half pair," three are "one and one-half pairs."

The article itself consists of two "leaves" which, when folded open, are ordinarily equal in width to height and the stock sizes refer to the opened hinge. When projecting finish requires clearance for a door folded back, the width of the butt must be increased. Wherever possible, this should be accomplished by also increasing the height to avoid special hinges.

Hinges or butts are made with fast or loose pin, fast or loose joint, 3 or 5 knuckles, with or without washers and ball bearings. Loose joint and loose pin butts permit taking down of door without removal of hinges. Loose joint butts have but one knuckle or bearing point

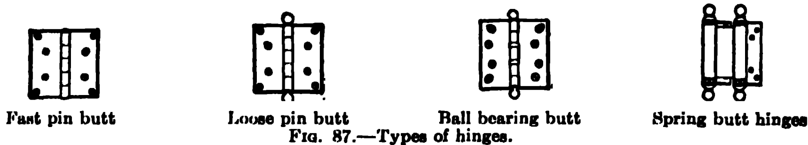


Fig. 87.—Types of hinges.

while loose pin butts have two or more. Consequently, loose joint butts are seldom used. Fast pin butts are employed where loose pin butts are impracticable, as in the case of transoms.

Bronze door butts are regularly made with steel bushings at all joints or bearing points, but can be had with exposed fiber washers, self-lubricating washers, or ball bearings at all joints. Sizes ordinarily run from 3 × 3 in. to 6 × 6 in. but larger sizes are produced. These butts are made in different weights—light, medium, heavy, and extra heavy—to accommodate differing weights and uses of doors. Sizes of butts are determined by the thickness of door and clearance required for trim or projecting caps of wainscots, etc., which should always be taken into consideration in determining sizes.

Fig. 88.—Automatic sash adjuster.

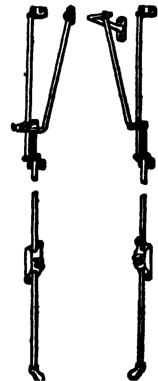
The pins of the butts in the heavier lines are so constructed as to prevent their working out of normal position and can be made so that removal is impossible except in one definite open position. This latter feature to prevent forcible entry by removal of doors (or French casements) is of value on entrance doors or sash opening out where hinges are exposed. Sizes under 3 × 3 in. are also furnished loose pin and fast joint but do not have washers and are made in different weights. Special types of hinges are made for water closet doors, double ands ingle acting doors. W. C. hinges are made both for single acting and double acting doors. Springs in hinge, close door or hold pen, as preferred.

For single acting or double acting doors, there are three distinct types of hinges. One consists of a box in floor, containing a spring and also acting as a lower pivot, a top pivot being placed in overhead jamb. The second type involves practically the same idea but with a box or case attached to door. The third consists of a pair of spring hinges attached to door and jamb. The first type is called a floor hinge and is made with and without checking feature. The second is termed surface hinge and is not made with checking device. The third is known as jamb hinge. The first and second types hold door open when swung beyond an angle of 90 deg.

Ball bearing pivots of varying sizes are regularly made for very heavy doors that are not actively used—as bronze entrance doors.

Specially patented butts are also made which permit adjusting the door after it is hung.

228. Adjusters.—Adjusters for use on casement windows, consist of a pivoted or grooved supporting plate, through which or in which a rod operates, one end of which is screwed to casement rail, the supporting plate being attached to window frame. They serve to hold casement windows open at any desired angle. One, working on the friction principle, is known as an automatic adjuster (Fig. 88). There are other types developed on this principle. Special devices are made, known as the concealed type, which involve a gear case in frame directly under heel of window and connecting with window by a pivot bearing through frame. A handle attached to casing, having a spindle extending through gear case completes the device. A similar outfit is made for outside shutters, the gear case being attached to sill on outside just under line of shutter and connected with shutter by a curved arm. With either of these adjusters, operation is effected without the necessity of opening screens or windows.


Fig. 89.—Transom lifters.

Adjusters for use on transoms, sometimes termed transom lifters (Fig. 89), consist ordinarily of rods moving through brackets—the latter screwed to casing—an arm from rod connecting with bracket attached to transom rail. Transoms can be hung on butts at top or bottom or on pivots on side or at top and bottom. The size and length of rod varies with the height

required. The standard sizes run ¼, 5/16, ⅜, and ½-in. diameter, and from 3 to 6 ft. or more in length. The material is wrought, not cast.

A concealed operator for transoms is also made, the only visible portion being the operating handle. This article is similar in mechanism to the concealed casement and shutter operator but in form quite different. The device consists of a unit plate concealed in and attached to casing to which is fastened a gear case. A toothed rod passes through gear case and connects with levers that are fastened to a pivot bearing. This bearing extends from the unit plate to heel of transom. The gear case is located near bottom of unit plate and plate is made of such length as to bring handle which enters gear case, about 5 ft. from floor. To permit use of concealed adjusters, work must be detailed in accordance with requirements.

Transom centers are designed for sash pivoted at sides or at top and bottom. When vertically pivoted, the lower and top of sash is usually rabetted and requires a center to fit rabett and also sash. These are regularly made suitable for ½-in. rabett and in varying widths to suit sash from 1½ to 2½ in. in thickness. They are also made with corrugated washers, capable of a friction adjustment and serve to hold sash open at any desired angle.

Chain door fasteners permit a partial opening of door, but door must be completely closed to release fastening. Therefore it cannot be tampered with from outside.

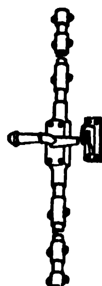
Door stops of either wood or metal are made for attachment to baseboard and also to floor. When attachment is made to marble, concrete, etc., expansion bolts are required. All are equipped with rubber bumpers, and some metal stops have hooks to hold door open.

Door holders are attached to door, operated by the foot, and hold door at any point of its swing.

Door checks are attached to door or to a bracket screwed to overhead jamb, made generally in six regular sizes, and act as door closers. A checking device is incorporated that prevents slamming without detracting from power.

229. Window Pulleys.—Window pulleys are made with three distinct kinds of bearings. The least expensive consists of a plain axle through wheel riveted to pulley case, and termed noiseless.

The roller bearing or anti-friction style is made with a series of round steel pins encircling axle and in which axle revolves. Ball bearings, as the name implies, consist of a ball retainer and hardened steel balls set in both sides of case to receive axle. Faces of pulleys are either square or round end and are made either of finished nonferrous metal or Japanned, galvanized, or plain iron for painting. Wheels are made 1¾, 2, 2¼, 2½, and 3 in. in diameter and are either cast metal or stamped. Pulleys with 2¼-in. wheel are recommended size for average good work.


Fig. 90.—Cremorne bolts.

230. Bolts.—Many varieties of bolts are made both in the rim and mortise types.

Extension bolts are so termed on account of having detachable bolt head—the latter fastened to rods of varying lengths. This permits the use of a top and bottom bolt of similar appearance but of differing lengths. Rod for top bolt should be of sufficient length to bring handle of bolt about 5 ft. from floor. This particular kind of bolt may be operated by the turning of a knob, by the slide of a knob, or by operation of a lever. In the latter case, lever is set flush with surface of bolt plate and can therefore be used on edge of door as well as on face. It is the proper type for use on folding doors or in any case where it is desirable or necessary to avoid projection beyond surface of door.

Cremorne bolts extend full length of door, operated by a handle located about 30 in. from floor and fastens door both at top and bottom (Fig. 90). The bolts are "handed" for right and left doors. Doors hinged on right hand side as seen from inside require R. H. bolts. If hinged on left hand side, a L. H. bolt. Pairs of doors with flat faces require bolts on each door, but if doors are rabetted, one bolt is sufficient. In the latter case, a bolt is frequently used on each door for uniformity of appearance. If one cremorne bolt is used, the opposite half should have extension bolts. Simplified Practice Recommendation No. 18 eliminates T-handle types.

Instead of being rabetted, double doors are more and more frequently being made with an astragal or mold which, secured to one door and overlapping the other, accomplishes the purpose of a rabett, namely, to avoid an open joint and yet allows the faces of the doors to accommodate themselves to regular or standard hardware.

Espagnolette bolts are designed for hinged sash occurring singly or in pairs. They fasten at top, bottom, and center and are made right and left hand.

Special types, known as "panic" bolts, are manufactured for use on doors leading from places of public assemblage and are so designed that pressure from the inside will liberate the mechanism.

Chain bolts, foot bolts, neck bolts, barrel bolts, etc. are too well known for more than casual mention.

231. Miscellaneous Hardware.—Coat and hat hooks, towel or regalia hooks, wardrobe hooks, and wire hooks are made in many sizes and shapes. Push plates are made in glass as well as metal.

Cupboard turns, screen door catches, drawer pulls, drop handles, shutter knobs, sash lifts, sash fasts, push buttons. letter-box plates, push plates, door pulls are all essentially necessary

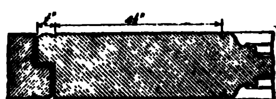


Fig. 91.

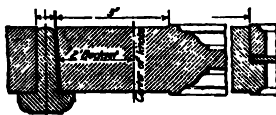


Fig. 92.

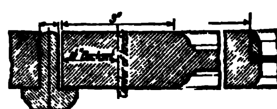


Fig. 93.

Fig. 91.—Double interior doors with rabbetted meeting stiles using bit-keyed lock for locks with standard backsets; stiles should not be less than 4½ in. on narrow side.

Fig. 92.—Double narrow stile doors with flat astragal meeting stiles using cylinder lock front beveled ⅛ in in 2 in.; regular backset 2 in.; the stiles should be not less than 3 in. Narrower backsets may be had on special order at an additional price.

Fig. 93.—Double narrow stile doors with flat astragal meeting stiles using bit-keyed lock with flat front, not beveled. Regular backset 1½ in. The stiles should be not less than 3 in.; other backsets may be had on special order at an additional price. For thicker doors, locks with beveled fronts may be had on special order at an additional price.

items in any building installation too numerous and generally understood to require especial mention.

When hardware is required for metal construction, it is necessary to furnish machine screws for purposes of attachment and to make all the items conform in size and location of screw holes to an exact standard. Templates of each item of hardware involved should be sent to sash and door manufacturer, as a guide in mortising and drilling

232. "Hand" and Bevel of Doors.—The "hand" of a door is always determined from the outside. The "outside" is the street side of an entrance door, and the corridor side of a room

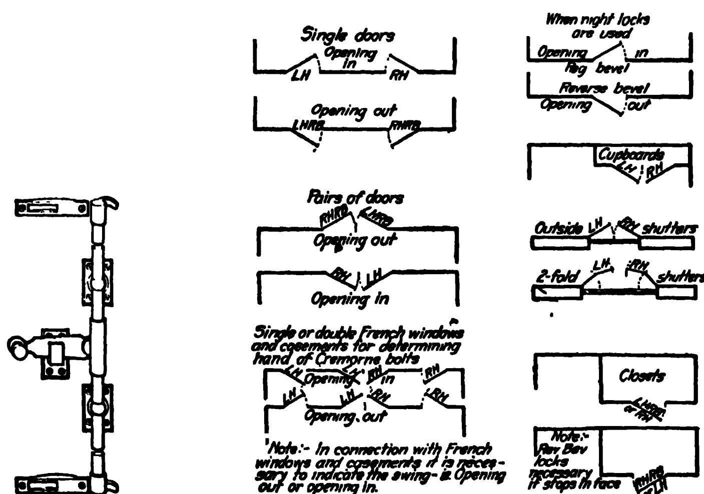


Fig. 94.—Espagnolette bolt.

Fig. 95.

door. The "outside" of a communicating door, from room to room, is the side from which, when the door is closed, the butts are not visible. The "outside" of a pair of twin doors (doors hung on both sides of a single opening) is the space between them.

The "outside" of a closet door is the room side, thus reversing the rule which applies in other cases. The foregoing definitions apply to sliding doors as well as to hinged doors.

If, standing outside of a door, the butts are on the right, it is a right-hand door; if on the left, it is a left-hand door. This, however, does not apply to casement sashes and outside blinds or shutters, where the point of view is assumed to be from the inside instead of the outside.

A door is bevelled when its edge is not at right angles with its surface, and a mortise lock for such door requires a bevelled front. This bevel is expressed by stating the thickness of the door and the distance which one edge drops back of the other. Two standards exist for bevels, one being ⅛ in. in 2 in., and the other being ⅛ in. in 2¼ in.—the former, as before stated, being the one most generally used.

The proper bevel of a door, or whether any is needed, is determined by the size of butt and the thickness and width of door. The result may be accomplished by bevelling the edge of the door, or, if its edge is left square, by leaving sufficient clearance between the door and its jamb. If the door is of fair width, and if the butt does not need to be very wide (to clear the architrave or other projections), it will be found that a square edge may be used without resort to an unduly open joint, thus permitting the use of a lock with regular front. The use of beveled front locks should be avoided where no real need for them exists.

If, standing outside, the door opens from you or inward, it takes a lock with a regular bevel; if opening outward, it takes a lock with reverse bevel.

As cupboard and bookcase doors always open out, locks for such doors are regularly made with reverse bevel bolts; therefore, as to such locks, it is unnecessary to specify "reverse bevel." The accompanying diagrams (Fig. 96) illustrate clearly the above descriptions, the abbreviations being R. H.—right-hand; L. H.—left-hand; Reg. Bevel—regular bevel; and R. B.—reverse bevel.

PART II
ESTIMATING AND CONTRACTING

SECTION 1

ESTIMATING STEEL BUILDINGS

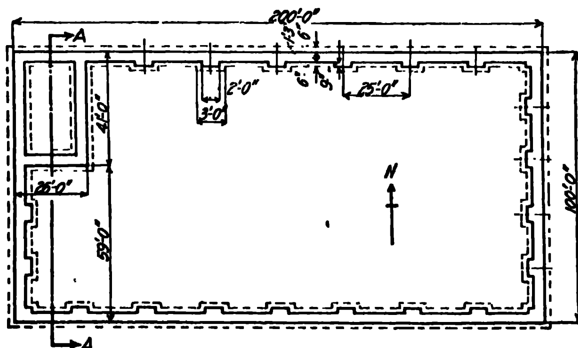
By Arthur E. Alitis

The object of this chapter is to outline the considerations which go to make up actual costs. Where unit costs appear, they can be used intelligently only as a criterion since it is not possible to establish other than approximate prices for building operations, due to market changes.

What is given under this heading applies directly to the estimating of simple factory buildings having a structural steel frame without fireproofing, but the methods described and considerations involved pertain to high office and other buildings of structural steel. Much may be learned from this chapter as regards estimating in general. Estimating of concrete footings, concrete floors, etc., is not considered, as the same rules apply as in the chapter following.

The item "material" in estimates usually includes all expenses incident to placing building materials at the site. Under the item "labor" is included all estimated field payroll expenditures. When carload shipments are estimated, "labor" includes unloading expense.

1. General Inspection of Building Site.—The consideration of the building site, with respect to the speedy and economical handling of materials from cars to their respective places in the finished building, is a most important one in the mind of the experienced building estimator. A large percentage of the jobs showing a loss to the contractor can be attributed to the lax consideration of the site. Two items are to be considered—railroad delivery and material storage facilities. Without proper consideration of both of these conditions, the cost of each and every operation in the entire building may exceed the estimated allowance.



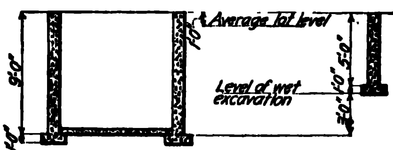


Fig. 1.—Foundation plan (interior piers omitted).

Materials are often bought in team lots delivered at the site when there is no switch track located on the building premises. The costs of materials delivered by team by local dealers—particularly large quantities of bulk materials, such as cement, sand, stone, brick, steel, and lumber—are usually compared with the cost f.o.b. cars, plus the teaming from track to site. These costs can be determined locally for each instance.

Sufficient available storage space to take care of the usual necessary material on hand at the building site means a great deal to the construction superintendent. The difference in cost between a job run under these conditions, and a job where, due to lack of room, materials are in the way of operations, has frequently eaten up the estimated profit. The work must run along smoothly or the superintendent will be unable to meet the estimate. The method for pricing labor operations to be carried on under crowded conditions is usually to allow for the increase in the unit price of each operation rather than attempt to enter a lump sum item in the estimate.

It is usually practical while at the site to investigate the local wages of the several building trades and also make note of the general labor situation. Lot levels, if omitted on drawings by designing engineer, should be obtained and placed on drawings by the estimator. Present incumbrances on site should be noted, also such details as building permits, street obstruction permits, water permits, etc.

2. Sample of Estimate for Foundation.—The following estimate of the cost of a building foundation (with the exception of the concrete work which is taken up in the section following) is given to illustrate the general form for listing, pricing, and extending the various units:

FORM OF GENERAL ESTIMATE

			Quantity	Price	*A* extension	*B* totals
General conditions:						
	Railroad track adjacent to building.					
	B. & O. delivery.					
	Adequate space for storing materials.					
	Water furnished by owner.					
	Nature of soil--sand, water present 5 ft. below ground level					
	Cinders for filling can be procured for a switching charge of 50c. per cu. yd.					
	Owner takes out all permits except street obstruction permits					
	Site is clear.					
Dry excavation—Foundation walls:			309 cu. yd.	$1 10	340–	
North:	1 wall $174^{0} \times 3^{3} \times 4^{0}$	2,262				
North:	1 footg $174^{0} \times 2^{3} \times 1^{0}$	392				
South:	1 wall $200^{0} \times 3^{3} \times 4^{0}$	2,600				
South:	1 footg $200^{0} \times 2^{3} \times 1^{0}$	450				
East:	1 wall $100^{0} \times 3^{3} \times 4^{0}$	1,300				
East:	1 footg $100^{0} \times 2^{3} \times 1^{0}$	225				
West:	1 wall $59^{0} \times 3^{3} \times 4^{0}$	767				
West:	1 footg $59^{0} \times 2^{3} \times 1^{0}$	133				
All walls:	19 pils. $3^{0} \times 0^{9} \times 5^{0}$	214				
	Labor at 1.10	8,343				
Dry excavation—Boiler pit:			250 cu. yd.	1.00	250–	
	1 pc. $45^{0} \times 30^{0} \times 5^{0}$	6,750				
	Labor at 1.00					
Wet excavation—Boiler pit:			200 cu. yd.	2 00	400–	
	1 pc. $45^{0} \times 30^{0} \times 4^{0}$	5,400				
Backfill:			258 cu. yd	50	129–	
N. wall:	2 pcs. $174^{0} \times 1^{0} \times 4^{0}$	1,392				
S. wall:	2 pcs. $200^{0} \times 1^{0} \times 4^{0}$	1,600				
E. wall:	2 pcs. $100^{0} \times 1^{0} \times 4^{0}$	800				
W. wall:	2 pcs. $59^{0} \times 1^{0} \times 4^{0}$	472				
Pit:	2 pcs. $30^{0} \times 2^{0} \times 9^{0}$	1,080				
Pit:	2 pcs. $45^{0} \times 2^{0} \times 9^{0}$	1,620				
		6,964				
Floor fill required:			175 cu. yd.	2 00	350–	
	1 pc. $197^{6} \times 97^{6} \times 1^{0}$	19,256				
	Outs:					
	19 pils. $2^{0} \times 0^{9} \times 1^{0}$. 29					
	1 pit. $24^{9} \times 39^{9} \times 1^{0}$ 984	1,013				
		18,243				
Surplus excavation—Spreading and tamping:			501 cu. yd.	.50	251 –	
	Dry excavation (walls) . 8,343					
	Dry excavation (pit).... 6,750					
	Wet excavation (pit).... 5,400					
	20,493					
	Less backfill........... 6,964	13,529				
		4,714				
Shoring to boiler pit:			600 pcs.	.60	360–	
	600 piles 2 × 6 × 7..................	4,200				
	10% waste....	420				
		4,620				
	Material 7 ft. at 6ct. = 0 42					
	Labor = 0.18					
	0.60					
Pumping and bailing:						
	Setting pump.		Allow		50–	
	Set and connect 55 well points.		55 pcs.	.50	28–	
						2,158

The estimator should bear in mind that the proposal tendered the prospective customer is based on the estimate, and when the obligations of either the owner or the contractor are in doubt, the contractor's assumption should be noted on the estimate so that it can later appear in the proposal. This is especially important in connection with miscellaneous items, such as water, permits, clearing site, etc.

In listing quantities no attempt is made for extreme refinement. Full length of wall for excavation on each side of the building is listed. Although the corners overlap, this is good practice for this class of work and goes to offset the irregularities incident to construction. Note that on account of the difference in unit costs for dry and wet excavation for boiler pit, this item has been separated into two parts. Extensions are figured to the nearest dollar. Columns A and B provide a means for grouping the operations of the different trades in the event that it is desirable to have these costs convenient for reference.

As the costs of transporting, unloading, and reloading equipment are the same for large or small quantities of work, and it is always desirable to keep unit costs on a comparative basis, all equipment is grouped on a Tool List and entered later in the estimate. The costs for handling equipment is then approximated direct from this list.

The take-off should also be made up so that every item may be readily identified (note column at left edge of sample estimate). A large percentage of designs are changed and require re-estimating; for this reason much time and inconvenience may be minimized.

3. Clearing Site.—It is well to have this item appear in the estimate even though no expense need be estimated. A detailed discussion of the estimating for expense of clearing site is hardly practicable due to the great variance of obstructions encountered.

4. Excavation.—The unit cost of excavating is governed by the kind of soil and the amount of water present. Using as a basis the cost of handling a firm, dry soil, the unit price may have to be increased: (1) for handling wet excavation, (2) when excavating through a re-fill of miscellaneous building debris that cannot be spaded, (3) when depth of excavating requires relays from platforms, usually about 6 ft. apart, and (4) when sand or other material with little or no self-retaining properties is present.

Different kinds of excavating should be listed separately to allow for the convenient use of varying unit prices. These excavating conditions having been established by the general inspection, the unit price must be fairly accurate. Similarly, when estimating caissons for heavy buildings, general inspection should determine whether ordinary well or pneumatic methods are to be estimated.

The steam shovel is usually estimated for making large cuts where surplus excavation must be hauled away. The excavating and loading is then accomplished by one operation.

5. Shoring.—Aside from the increased costs of excavating operations, it is often necessary to provide temporary support for earth walls. The costs of wood shoring are developed similar to costs of shores or forms for concrete work, and reference should be made to the next chapter for details. The salvage is usually very small and, unless a second use for the lumber is predetermined, the total cost of the material is usually charged.

6. Pumping and Bailing.—Pumping and bailing are generally figured separately for each pit, basement, or other unit. The approximate amount of water to be encountered, the nature of the soil and work to be carried on, serve to determine the most practical kind of equipment. The estimator can readily develop an accurate allowance for the material by keeping in mind the equipment he has available. The material unit usually consists of fuel unless the necessary pumps are not at hand, in which case rental will greatly increase the amount to be estimated. The labor unit would include the setting and maintenance of pumps.

7. Backfill.—Backfill includes the cost for refilling the oversize excavation made to allow for concrete forms, etc. The quantities can be listed from the drawings. The estimated cost per cubic yard usually runs about 50 % less than the excavating unit, as the ground is well broken up and invariably the original material excavated is close at hand.

8. Disposal of Surplus Excavation.—The construction of the substructure will generally net a yardage of surplus excavation, the disposition of which depends upon the level of the floor area. Ground levels are taken by dividing the entire surface into squares and reading the rod at the corner of every square. These levels will then determine whether it is necessary to estimate either the grading or the filling of the lot. Should the site be low, the surplus excavation is usually estimated to be spread in addition to such fill as must be procured elsewhere. The source and cost of this additional fill must be the result of investigation of local conditions.

Should the lot levels prove to be high, the disposition of surplus excavation must be considered in the estimate.

9. Structural Steel.—Structural steel costs are frequently listed in the General Contract estimate in summarized form under the headings—*Material* and *Erection*. Material includes estimated expense incident to manufacture and delivery at the job site. Erection includes expense estimated to unload, erect, and paint structural steel, as well as all erecting equipment costs.

Structural steel costs are based on weight. The following practice to be used for the invoicing of bridges, buildings, and other structures, has been adopted by the *Structural Steel Society* as representing standard practice to be followed in all cases where other provisions are not made in the contract or specifications. These items have a direct bearing on the price and should therefore be of assistance to the estimator.

Weights.—Structural steel sold at a unit price per pound, hundred weight, or ton, shall be invoiced on estimated, theoretical weights, based on the detail drawings and shop bills, using

(*a*) Rectangular dimensions for all plates.

(*b*) Overall lengths for all structural shapes, and making no allowance for the weight of copings, clippings, millings, punchings or borings.

Overrun.—To the theoretical weight of all sheared plates, there shall be added an allowance for overrun in weight, calculated from, and equivalent to, the percentage of overrun provided for in the A.S.T.M. Standard Specifications for structural steel.

Rivets.—All shop rivets used in the structure shall be invoiced at the following average weights.

(*a*) Rivets ½ in. diameter— 20 lb. per 100 rivets.

(*b*) Rivets ⅝ in. diameter— 30 lb. per 100 rivets.

(*c*) Rivets ¾ in. diameter— 50 lb. per 100 rivets.

(*d*) Rivets ⅞ in. diameter—100 lb. per 100 rivets.

(*e*) Rivets 1 in. diameter—125 lb. per 100 rivets.

(*f*) Field rivets to be invoiced at actual weights.

Paint.—To the total weight of the structural steel, as determined by the above methods, there shall be added an allowance for the weight of the paint, of 8 lb. per ton of structural steel, for each coat.

Field Rivets and Bolts.—In furnishing a bill for structural steel for any structure, where no provision to the contrary is made, the fabricating shop will furnish the following rivets or bolts for field purposes.

(*a*) *If the structure rivets in the field*, the fabricating shop will furnish sufficient rivets of suitable size, plus 10% allowance for waste, for all field connections, steel to steel; but will furnish no bolts, except for such connections as it will not be possible to rivet.

(*b*) *If the structure bolts in the field*, the fabricating shop will furnish sufficient bolts, of suitable size, plus 5% allowance for waste, for all field connections, steel to steel, but will furnish no rivets.

(*c*) *No miscellaneous carpentry* or masonry bolts will be furnished by the fabricating shop in any case, unless by special provision, for connecting in the field, wood to steel, wood to wood, or wood to stone, etc.

(*d*) *Erection, or fitting up bolts*, for the use of the steel erector, are considered as being erection equipment and will not be furnished by the fabricating shop, unless by special provision.

The first step in estimating structural material is to carefully examine drawings and if odd, unobtainable sections appear in any of the members, a redesign is made, using stock on hand. In the designing of structural steel, sections can frequently be slightly changed to conform to material in stock without incurring any disadvantage. This redesigning is seldom necessary when estimating mill deliveries.

The sequence of listing members in the take-off is about the same as that for erection. The main units are always listed first.

An approximation must be made of the weights of many of the details, as in general practice these may not appear on the design drawings. This part of the estimating must necessarily be done by one familiar with structural fabrication. When minor members appear in quantity, the exact dimensions are usually developed.

The majority of shops do not have their own foundries for furnishing castings but as cast iron is used extensively in many standard shapes in conjunction with structural steel, it can be conveniently and economically purchased with the steel. The most commonly used castings are generally kept in stock.

Starting with columns of which there may be several of similar design and construction—except for minor details, such as punching, small connecting angles, etc.—the materials are listed first for one column and the weights multiplied by the total number of duplicate columns.

If two or more types of columns appear in the design, there will be as many detail lists of material. Each list is multiplied by the total number of columns of that type.

As the main sections of columns or other members contribute most of the estimated weight, the lengths of main members should be figured with some degree of accuracy.

The percentages used for estimating the weights of details on members of common construction are approximately as follows:

	Rivets	Details
Beams	1%	*
Roof trusses	3%	15 to 20%
Girders	5%	10%
Latticed columns	3%	10 to 15%
Plate columns	4%	10%
Girts	3%	10%

* Beam details vary considerably. Weights of standard connections are readily obtainable.

These are average values. Frequently a general approximation of 4% of the weight of all members is made to determine weight of rivets, and the weight of details is taken at 20% of all main members.

DETAIL TAKE-OFF

No. of pcs.	Size	Length	Weight per lin. ft.	Is, [s	Ls	Small Ls	Plates	Flats	Rivets	Totals
	20 Trusses T1									
4	Ls 5 × 3½ × $\frac{5}{16}$	40 9	8 7		1,425					
2	Ls 3½ × 3 × $\frac{3}{8}$	81 5	7 9		1,290					
2	Ls 2½ × 2 × ¼	2.0	3 7			15				
2	Ls 2 × 2 × ¼	6.3	3 2			40				
2	Ls 2½ × 2½ × $\frac{5}{16}$	8 7	5 0			85				
2	Ls 2¼ × 2¼ × $\frac{5}{16}$	6 2	4 5			55				
2	Ls 2½ × 2½ × $\frac{5}{16}$	8 9	5 0			90				
4	Ls 3 × 3 × ¼	8 3	4.9		165					
2	Ls 2 × 2 × ¼	7.6	3 2			50				
2	Ls 2½ × 2 × ¼	4 0	3 7			30				
	Details 20%						650			
	Rivets 3%								115	
	Weight of one truss				2,880	365	650		115	4,010
	Weight of 20 trusses				57,600	7300	13,000		2,300	80,200
	Floor beams									
40	Is 10″ at 25 #	16.0		16,000						
80	Std. Conn. 10″ I				1,280					
6	Is 12″ at 31½ #	20.0		3,780						
6	Ls 3 × 3 × ½	19.5	9.4		1,100					
8	Bars 6 × ½	19.5	10.2					1590		
12	Std. Conn. 12″ I				275					
	Rivets 1%								240	
				19,780	2,655			1590	240	24,265
	Totals			19,780	60,255	7300	13,000	1590	2,540	104,465

The tabulation of the weight extensions as practiced in the above take-off is made necessary by the different mill costs of sections. The general classification of common sections according to price per hundredweight is as follows:

Shapes	Size	Price
I-beams and channels	3 to 15" inclusive	Base
Large I-beams	Over 15"	Plus 10c.
Angles	3 to 6" on one or both legs by ¼" thick or more	Base
Large angles	Over 6" on one or both legs	Plus 10c.
Tees	3" and over	Plus 5c.
Zees	3" and over	Base
H-columns		Plus 10c.
Light section beams		Plus 5c.
Bars and Bar Sizes	**Size**	**Price**
Rounds and squares	¾ to 3"	Base
Rounds and squares	Other than ¾ to 3"	Varies
Flats	1 to 6" wide by ⅜ to 1" thick	Base
Flats	Other sizes	Varies
Small angles	Under 3" on one or both legs	Varies
Small channels	Under 3"	Varies
Tees	Equal leg tees under 3"	Varies
Plates	**Size**	**Price**
Plates	¼" and heavier up to 72" wide	Base
Plates	3/16" under 72" wide	Plus 10 c.
Wide plates	¼" over 72" but under 100" wide	Plus 10c.
Wide plates	¼" and heavier 100" or more wide	Plus 30c.

In addition to the above extras, there may be cutting charges which, however, are a direct fabricating expense and are included in the estimate of shop labor. The costs noted above represent the mill prices of the different sections and from a fabricator's standpoint are a material cost. The weights of standard sections and the extra prices will vary from time to time

The summarizing of the material listed in the take-off is simply the extending of each class at the unit price. The difference in cost between mill and stock deliveries occurs in these prices. The margin for stock delivery is generally about $15 per ton.

The estimate, after adding the approximated costs of manufacturing and transportation, will have the following general form:

FORM OF STEEL ESTIMATE

			Lb.		Unit per cwt.		
		Is, [s	19,780	at	2.45		
20 trusses Tl	80,200	Ls	60,255		2 45	2,139.71	
Floor beams	21,265	Small Ls	7,300		2.45		
	104,465 lb.	Plates	13,000		2 65	344 50	
		Flats	1,590		2 35	37 37	
		Rivets	2,540		3.75	95.25	
		Shop paint	104,465		.05	52 23	$2660.06
		Freight					193.68
		Shop labor at $15 per ton				780 00	
		Drawings at $2 per ton				104 00	
						884 00	
		Administration, insurance, and overhead, 100%				884 00	1768.00
	Manufacturing cost, f.o.b. destination, mill basis						$4630.74
		104,465 lb. at 75c. per cwt					783 49
	Manufacturing cost, f.o.b. destination, stock basis						$5414.23

In connection with freight rates which can easily be procured from railroad freight offices, a reduction based on milling in transit may sometimes be estimated. For instance, in case of a structure estimated for mill shipment, a rate may be frequently used based on hauling steel

from mills to building site plus an increase for what may be called a stop-over privilege at the point where material is to be fabricated. This rate would affect a saving over the combined freight rates from mills to fabricating shops and fabricating shop to destination.

Under the present tariff regulations the stop-over privilege is limited to one year after receipt of inbound property at fabricating point and the cost for this privilege is 1½c. per hundredweight.

The following sample of estimate of shop fabricating costs will give an idea of the increased values as well as a general method for computing:

Trusses 48,004 lb.	2 Ls 3"x3"x¼"; 1L; 2 Ls; 56'-0"; 14'-0"		22 Pieces @ 20.00			440.00
Columns 31,350 lb.	1-10" I @ 25 # Base and cap		22 Pieces	30'	97.50	160.00
	1-8" B.G. @ 32½ # Base and cap		11 Pieces	30'	62.50	
Purlins and eave struts 35,840 lb.	1-5" [@ 6½ #	P	220 Pieces	18'	110.50	200.00
	1-6" [@ 8 # / 1-∠ 3"x3"x¼"	]⌈	20 "	18'	50.00	
	1-5" I @ 9¾ #	P	20 "	18'	25.00	
	1-∠ 3"x2½"x¼" lookouts		52 "	3'	15.00	
L-Bracing 12,714 lb.	2-Ls 3½"x2½"x¼"	⌉⌈	6 Pieces	18'	22.50	135.00
	2-Ls 3"x2½"x¼"	⌉⌈	12 "	13'	30.00	
	1-∠ 2½"x2"x¼"	P	18 "	8'-9"	10.00	
	2-Ls 2½"x2½"x¼"	┘┌	12	18'	22.50	
	1-∠ 2½"x2"x¼"	P	28	18'	12.50	
	2-Ls 3"x3"x¼"	┘┌	20	18'	37.50	
Rods 6,329 lb.	1-Bar ¾" φ		+122 Pieces	24'-27'	62.50	92.50
	1-Bar ⅝" φ		+240 "	5'	30.00	
134,237 lb.						1027.50



FIG. 2.

The letter "P" denotes plain material incurring only cutting and punching expense. Sections are sketched opposite the various items to make the general assembly immediately apparent to the person in charge of pricing. The costs as given include all operations of measuring, laying out, templets, etc.

Costs of shop drawings are generally approximated by the ton of steel and may run from $0.50 to $10 per ton. Like the fabricating costs, these are governed largely by the amount of duplication in the members fabricated.

Assuming that the unit costs used when pricing material are based on mill shipments, it may be desirable to arrive at the estimated cost for delivery out of stock. An item covering this difference is then entered in the estimate as has been done in the above case.

10. Erection of Structural Steel.—A thorough inspection of site and local conditions must be made before starting to estimate. Power usually plays a great part in the erection of the steel and if it can be obtained cheaply in the form of steam, electricity, gasoline, oil, or compressed air, notations to that effect are made on the estimate sheet, a sample of which follows:

No compressed air or steam available at site.		
Equipment		
Unload and reload.........allow		$ 150.00
Setting and dismantling derrick (10 ton 70 ft. boom).........allow		170.00
Moving.........allow		50.00
Steel		
Unloading—300 tons at 1.00.........		300.00
Bulling—300 tons at 1.00 (70 ft.).........		300.00
Erecting—300 tons at 8.00.........		2,400.00
Plumbing.........allow		50.00
Rivets—300 tons, 20 per ton = 6,000 rivets at 15c.........		900.00
Bolts—300 tons, 3 per ton = 900 bolts at 7c.........		63.00
Paint—300 tons at 1.50.........		450.00
Superintendent—5 weeks at 60.00.........		300.00
Engineer—5 weeks at 50.00.........		250.00
		$5,383.00
Workmen's and Liability insurance, 20%.........		1,076.60
		$6,459.60
Railroad fares—4 men, 2 ways at 4.00.........	$ 32.00	
Freight on tools and equipment—2 cars, 2 ways at 20.00.........	80.00	
Coal for raising 300 tons steel.......... 8.0 tons		
Coal for driving 6000 rivets ....12.0 tons		
20.0 tons at 6.00	120.00	
Paint—120 gal. at 3.50.........	420.00	
Miscellaneous lumber.........	30.00	682.00
		$7141.60

Add percentage for overheads, business generals, and depreciation of tools.

As the insurance is based on payroll expenditure, it is necessary to segregate all field payroll items. The estimated equipment costs must necessarily be based on the proper kind of apparatus for the type of structure to be erected. Stiff-leg and guy derricks are most commonly seen on building erection. The term "bulling" is used to indicate moving or dragging structural steel with crow bars, dolly rollers, or other make-shift methods when the haul is not long enough to justify teaming or other more regular methods of transporting.

The cost of setting up a stiff-leg derrick on the ground under favorable conditions will run from about $125 for a 70 to 85-ft. boom, 10-ton rig, to $300 for a 100-ft. boom, 20-ft. outrigger, 25-ton capacity derrick. The comparative cost for setting up a 95-ft. boom, 15-ton capacity guy derrick, with minimum of six 1-in. cable guys is from $200 to $250. An 85-ft. steel gin pole on the same basis would cost about $80. These costs are based on a wage of 87½c. an hour. 50% should be added for dismantling. ¾-in. diameter field rivets in factory buildings run from 12 to 15c. a piece. Simplified scaffolding and concentrated rivets as are common in bridge work or heavy loft buildings will tend to decrease these costs considerably. Labor costs for bolting are from ½ to ⅓ those for riveting.

The painting of structural steel is approximated by the ton of material to be covered. Light weight steel will net additional and more scattered surfaces than heavy construction. Extra scaffolding often raises the price 300 %. Proportions for material and labor noted in above estimate are for medium weight shop buildings.

The estimated quantity of coal depends in turn upon the estimated tonnage and the number of field rivets. For the first type of structure noted in the accompanying table, the coal would probably figure at the ratio of one ton for every 50 tons of steel, plus one ton for every 400 to 600 rivets depending upon the proper number of riveting gangs. When only one gang is working, 50 % more coal is consumed.

An item covering railroad fares for such workmen as cannot be procured at the site is usually entered in the estimate. This item is mostly a matter of judgment of general building conditions and in unfavorable building localities it may even be necessary to allow for the costs of commissaries and bunk houses.

Expense due to planking and use of timbers must be foreseen by the estimator. Particularly in connection with high loft building erection is temporary planking necessary around

the derricks and at floors where smaller members are piled and sorted. Timbers are usually necessary for compression members in setting up derricks. Timbers are also frequently estimated when constructing additions to present buildings. It is often found necessary to support wall bearing members until new material is set in place.

Approximations of Weights of Structures and Number of Shop and Field Rivets

These are taken from actual structures and will furnish a basis for rough approximation of the different types of steel skeletons. The weights include the steel frame only, and the crane runway when noted. None of the figures include weights of cranes or machinery.

Type of building	No. of shop rivets per ton	No. of field rivets per ton	Weight of steel per sq. ft. of structure (pounds)
Saw-tooth shop bldg., gypsum tile roof, 24 ft. to bottom chord of truss, 5-ton cap. runways	90 to 120	25	12 to 16
Same building, 16 ft. to bottom chord of truss, no crane runways	90 to 120	25	11 to 15
Flat roof factory bldg., gypsum tile roof, 40 ft. to bottom chord of truss, 5-ton crane runways	100 to 130	19	14 to 20
High and low bay factory bldg., 24 ft. to bottom chord of truss, 5-ton crane runways	90 to 130	22	14 to 18
Office buildings	100 to 200	22	*2 to 4
Foundry cupola floor framing including columns and checkered steel floor plates	100 to 200	32	35 to 60
Yard crane runways			
40-ft. span—16 ft. to rail—10-ton cap			300 **
40-ft. span—16 ft. to rail—20-ton cap.			500 **
60-ft. span—24 ft. to rail—10-ton cap.	130 to 200	30	350 **
60-ft. span—24 ft. to rail—20-ton cap.			600 **
80-ft. span—32 ft. to rail—20-ton cap.			500 **
80-ft. span—32 ft. to rail—30-ton cap.			725 **
Head frame over shaft of iron mine 125 ft. high. 15 tons working load.	100 to 200	40	175 tons ‡ 400 tons §

* Weight per cubic foot of building.
** Weight per lineal foot of crane travel.
‡ Total weight—light.
§ Total weight if equipped with crushers, conveyors, etc.

11. Brickwork.—Brickwork is priced by the unit of 1000 brick (abbreviated M). A simple, accurate method for arriving at the number of brick is to list the area and thickness of each wall. Using standard size brick which are 2¼ × 3⅞ × 8 in., an average of 7 bricks is estimated for each square foot of wall of thickness equal to the width of one brick. If the thickness of the wall is two bricks wide, then 14 bricks per square foot are estimated, etc.

Thickness of wall	Number of brick estimated per sq. ft.
1 standard brick width—4 in.	7
2 standard brick width—8 in.	14
3 standard brick width—12½ in.	21
4 standard brick width—17 in.	28
5 standard brick width—21 in.	35

The estimated number of brick in a building is frequently designated as "wall count." This term indicates that the total wall areas have been considered without deductions for openings, such as doors and windows. It is assumed that the expense for bricking jambs, etc., around

these openings is the same as the cost would be for building them solid. While this assumption may be correct, the result does not indicate the exact amount of material to be purchased. The following detailed unit cost is intended for pricing a take-off in which all openings 2 × 2 ft. or larger have been deducted. A feature for adjusting the number of brick estimated with the varying thickness of the mortar joints that may be specified, is essential. This adjustment can be made when compiling the unit price. Assuming that a standard size common brick is to be used with a ½-in. joint, the unit cost per M is made up approximately as follows:

Brick f.o.b. destination	$13.50 per M	
Unloading	1.50	
	$15.00 per M	
910 brick at $15 per M		$13.65
⅛ bbl. cement at 2.40		0.30
1 part lime, 1¾ bu. at 0.60		1 05
3 parts sand, ½ cu. yd. at 1.46		0 73
Water		0 12
Labor (mixing mortar and laying brick)		12 65
Scaffold material		1 00
Scaffold labor		2 00
		$31.50

When a ½-in. joint is estimated, there are actually 6.37 brick in 1 sq. ft. of wall. In order to avoid using this ambiguous fraction in numerous extensions, it has been assumed that seven brick occur in each square foot of wall as noted in above table. Therefore, for each 1000 brick developed by the take-off, only $\frac{6.37}{7.00}$ of 1000, or 910 brick, will really be used. This then is the number of brick per M estimated, that will need to be purchased, and has accordingly been used in arriving at the unit price per M.

A simple method that may be used for the development of this actual number of brick required for 1 sq. ft. of wall of thickness equal to one brick width, is to lay out on a drawing board 1 sq. ft. of wall including only stretcher courses. Another square foot of wall is then sketched showing only header courses. As these walls are but one brick width in thickness, the amount of brick in each is readily determined by dividing the area of the exposed faces by the area of one side of the size brick estimated. If a header course is specified at every fifth row, then the value of the number of brick in the stretcher sketch is 4 times that for the number of brick developed in the sketch showing headers. The average number of brick per square foot of wall is then determined by adding 4 times the number of brick appearing in stretchers to the number shown in headers and dividing by 5.

This computation can be made for any size brick and although the result is not 100% correct, it is sufficiently accurate for any practical purpose. Further refinement would be offset by variances occurring with field operations and would be of little practical benefit.

The cost of walls constructed of face brick backed up with common brick is generally estimated by first listing the entire wall as though it were of one kind of brick. A second take-off is then made of the face brick. This is subtracted from the whole to obtain the number of common brick.

The unit cost for walls of brick veneer, usually a single thickness of only stretcher courses, often includes the metal ties for bonding the brick to the body of the wall. The number of brick occurring in each square foot of this veneer wall as well as in English, Flemish, or any of the other numerous bonds, is readily determined by the proper manipulation of the values developed by the sketches of stretcher and header courses as explained above.

When constructing sills, corbels, soldier courses, etc., the extra labor may be estimated by allowing from 12 to 18c. per lineal foot in addition to the cost already appearing in the estimate, by including these quantities with the straight wall work. Arches likewise entail extra costs. Frequently a temporary wooden support must be built and an item of carpentry is included.

The firing of a kiln of common clay generally results in a percentage of extra hard-burned, slightly undersize bricks, which, when necessary, may be bought for a premium covering the cost of selecting, usually about $1 per M.

In determining the labor cost of laying brick, it is well to refer to the plans to ascertain if much cutting of brick be necessary. Gable end walls with sloping tops are bound to increase the labor unit. Corners, pilasters, reveals, etc., all retard the progress of a mason gang. As all masons in the squad should be ready simultaneously for the raising of the chalk line, the best bricklayers are usually placed at the corners. Especially when working from the interior side of the wall, there must be considerably more brick apportioned to the corner man than to those along the straight wall due to the space required by the mason to carry on his work. The construction of the building with regard to these features will greatly affect the unit labor cost allowed for bricklaying.

A considerable variance in the cost of mixing mortar makes discussion of that branch of masonry estimating rather difficult. It has been the writer's experience that where one mixer can supply mortar for 5 masons, another under the same conditions may provide for 15. It may be required to find what part of the labor cost of brick-

laying is estimated for mixing mortar. A fair average would be to figure one day's wages for the mortar mixer as furnishing material for 7000 brick. 13½ cu. ft. or ½ cu. yd. of sand is commonly estimated to provide mortar for laying 1000 brick, and may be used as the basis of material quantities. Should the specifications call for a 1-3 or 1-4 mix, the number of bushels of lime are determined by proportioning accordingly. As a bushel contains 1.2444 (1¼) cu. ft., the quantity of lime required is a simple computation. Again, if a cement gaged lime mortar is specified of 1-4-16 proportions, the basis of quantities is the 16 parts of sand. Let the 16 parts equal ½ cu. yd. and solve the other two volumes accordingly.

Referring to the sample cost for 1000 brick, the proportion of the 1¾ bu. lime and ½ cu. yd. sand will be found to be approximately as 1-6, whereas, the mixture is designated 1-3. This difference is caused by the practice of estimating lime in the dry bulk state in which it is usually purchased. Slaking of lump lime nets about twice as much lime paste, which is the basis of the proportions.

A wall of face brick is usually laid with colored mortar. The cost of the coloring per 1000 brick is added in the unit cost of the brickwork before extending. In the case of a wall combining face and common brick, where colored mortar is used only for the face brick, it is necessary to furnish the masons with two kinds of mortar. This is somewhat of a nuisance and necessitates a slight increase in the unit estimated labor cost. As is the case for practically all coloring pigments, the amount of mortar color depends upon the color and shade to be developed. For medium effective shades, an average of 40 lb. double strength, or 60 lb. single strength, is estimated for every 1000 brick. As far as the mortar is concerned, the coloring is a matter of material cost only. An increase should be made in the estimated unit cost for bricklaying when a light face brick is used with a dark mortar, or vice versa. These color combinations require care to be taken when distributing materials along the scaffold and also when building the wall so that there will be no discoloration of an expensive brick that is used ostensibly for the sake of appearance.

The scaffold material item of $1 as it appears in the detailed estimated unit cost of 1000 brick is not intended to cover the cost for purchasing scaffold required to lay 1000 brick but covers the estimated deterioration of the contractor's equipment on hand. Due to the weight of materials, the mason requires a substantial scaffold. An accurate estimated cost of erection must be the result of experience in the class of work to be encountered.

12. Steel Sash and Operators.—The area of steel sash is listed in the estimate and the price per square foot is applied separately to each different class. An estimator familiar with market prices may be able to approximate a fairly accurate price per square foot for steel sash including glass and glazing complete, but as a rule it is advisable to take quotations from sash manufacturers particularly when large quantities are considered.

Although sash are hardly ever sold by weight, it furnishes in conjunction with the number of joints a good criterion for the comparative price, as sash with small size lights weigh more than sash with large size lights, and the increased number of joints and ventilators increase the labor cost of production.

The estimating of operators for steel sash is generally based on a unit of one lineal foot. There are many different makes of these operators on the market with a wide range of prices, like most specialties. For this reason the general contractor usually takes quotations to determine the amount to be allowed in the estimate.

13. Glazing Steel Sash.—Glass and putty are the two common materials included in the glazing estimate.

The procedure for taking off and pricing common glass as well as other materials, must conform to the general methods of marketing. Glass is usually stored in cases, the sizes and number of pieces in a case being found on most any stock list. The areas of sheets of the same texture in standard lengths and widths up to 40 in. are listed in one group. Glass over 40 in. wide costs about 10% more on the basis of area, and is therefore listed separately. When estimating odd sizes, the cost of the next larger standard size is taken plus 10 % for recutting. Ventilator glass is usually of special size as the lights at top and bottom of ventilators are ⅞ in. shorter and the lights at sides of ventilators are ⅞ in. narrower than the standard lights. Ventilator lights not touching at top, sides, or bottom of ventilator, are generally of same dimension as the main stationary lights. ¼-in. wire ribbed glass costs about 30 % more, and factory ribbed glass costs about 30 % less than double strength (D.S.) AA grade clear glass. Opaque glass as a rule is cheaper than clear glass as the imperfections cannot be as readily detected.

Approximately 1 lb. of putty is required to glaze a 14 × 20-in. light. ½ lb. of putty is generally estimated for every square foot of standard side wall type sash, or 1 lb. for every 6 lin. ft. of stopping. The size of the openings in monitor sash varies greatly, and approximation of putty is hardly feasible from the basis of area. One pound will spread from 4 to 6 lin. ft. In all cases, the above values include both the puttying and back-puttying necessary to prevent the glass from bearing directly against the steel.

Steel sash are usually estimated to be glazed after erection. Having no separate frames, sash are set when the wall is built. A large steel sash glazed before erection would be a delicate article to handle and more than likely most of the lights would be knocked out by the various tradesmen working on the upper part of the structure.

The general estimated unit cost per square foot is often made up as follows:

¼-in. wire ribbed plate	$0.30
Putty, ½ lb. at 6c. per lb.	0.03
Labor glazing / Labor scaffolding	0.08
	$0.41

Before using the above unit costs, from 2 to 5% is added to the net estimated quantity of glass commensurate with the amount of shipping and handling. When glass is shipped by rail, material cost includes freight to site and labor cost is added for unloading.

14. Corrugated Iron or Steel.—Corrugated iron or steel is sold by the hundredweight. As estimated for steel buildings, however, it is conveniently taken in units of 100 sq. ft. The design drawings often show the size and position of each sheet, thereby simplifying the taking-off of quantities. The estimating of surfaces from drawings not showing the individual sheets may not be quite as accurate. The net area to be covered is listed in the take-off, plus an allowance of from 10 to 30% for side and end laps depending upon the surface slope with regard to weather. The standard corrugations are 2, 2½, and 3 in. from peak to peak of each ridge. Common stock sizes are 27½ in. wide and 5, 6, 7, 8, 9, and 10 ft. long. This width sheet covers a net strip 2 ft. wide, making a customary lap of 1½ corrugations. The end laps range from 6 in. on a ¼-in. pitch roof to 3 in. for vertical walls. A sheet of composition roofing is sometimes laid under the metal when covering roofs of less than ¼ pitch. Corrugated covering may be fastened by steel clips bent around the supporting members, or by nailing to wood nailer strips.

The gross number of squares of corrugated iron is extended at the unit price made up somewhat as follows:

Material—1 sq. 24 ga. galv. standard 126 lb. at $8.20 per cwt.		$10.33*
Fasteners		0.60
Labor (unloading 0.07, application 2.53)	2.60	
Generals, overheads, etc., 70%	1.82	4.42
* Includes freight.		$15.35

The item of labor varies greatly with the height of the application and the surface with respect to number of openings. The price used would apply for favorable conditions—that is, to a low structure with a moderate number of windows. The labor would need to be doubled or trebled when estimating high surfaces broken by numerous doors and windows.

15. Carpentry.—Waste is a big factor in the estimating of lumber. Full size boards are rough, and dressing or planing will naturally reduce the covering values so that an extra percentage must be allowed. The increased quantities due to waste are included in the material take-off with the result that both material and labor costs are based on the gross amount of material estimated.

When boards must be cut to odd lengths, there is another element of waste. The common standard mill lengths of lumber are from 10 to 30 ft. in multiples of 2 ft. Sticks 9 ft. long would be estimated as 18-ft. pieces cut in half. A stick 9 ft. 2 in. long may be cut from a mill length board of 10 ft. Long lengths of lumber cost more per thousand board feet than short lengths and must be so considered when determining nearest standard multiple of odd length required. Lengths of 10, 12, 14 and 16 ft., of like section, usually cost the same with an advance in unit price for each additional 2 ft. For instance, if the unit cost of 28-ft. lengths is 10% more than 16-ft. lengths, it is more economical to waste up to 10% more lumber in using the 16-ft. stock. Lumber should be so separated when listing in the take-off that pieces of different lengths and consequent varying costs can be priced separately.

The table[1] on p. 1092 should be of assistance in determining the number of boards required to cover the widths of various constructions that may be shown on plans. The lengths of the boards estimated as noted in the preceding paragraph must be considered with respect to the spacing of supports.

The quantities of nails often estimated for various carpentry are:

1000 laths, 7 lb. 3 d. fine; or for 100 sq. yd. of lathing, use 10 lb. of 3d. fine.
1000 sq. ft. beveled siding, 18 lb. 6d.
1000 sq. ft. sheathing, 20 lb. 8d. or 25 lb. 10d.
1000 sq. ft. flooring, 30 lb. 8d. or 40 lb. 10d.
1000 sq. ft. studding, 15 lb. 10d. or 5 lb. 20d.
1000 sq. ft. 1 × 2½-in. furring, 12 in. centers, 9 lb. 8d. or 14 lb. 10 d.
1000 sq. ft. 1 × 2½-in. furring, 16 in. centers, 7 lb. 8d. or 10 lb. 10d.

[1] Originally compiled by J. J. Edwards.

No. of Pcs.	8" Shiplap Y. P.	10" Shiplap Y. P.	10" Grooved roofing	6" Drop siding Y. P.	8" Drop siding Y. P.	4" Bevel siding (3" to weather) redwood pine	6" Bevel siding (5" to weather) redwood pine	4" Ceiling Y. P.	6" Flooring Y. P. W. P.	4" Flooring fir, maple, Y. P.	3" Flooring oak, maple	2½" Flooring ⅜" thick. 2¾" Flooring 1³⁄₁₆" thick. Oak, maple	2" Flooring ⅜" thick. 2¼" Flooring 1³⁄₁₆" thick. Oak, maple	1" Flooring ⅜" thick. Oak, maple
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1	7"	9"	9"	5¼"	7¼"	3"	5"	3¼"	5¼"	3¼"	2¼"	2"	1½"	⅞"
2	1' 2"	1' 6"	1' 6"	10½"	1' 2½"	6"	10"	6½"	10½"	6½"	4½"	4"	3"	1¾"
3	1' 9"	2' 3"	2' 3"	1' 3¾"	1' 9¾"	9"	1' 3"	9¾"	1' 3¾"	9¾"	6¾"	6"	4½"	2⅝"
4	2' 4"	3' 0"	3' 0"	1' 9"	2' 5"	1' 0"	1' 8"	1' 1"	1' 9"	1' 1"	9"	8"	6"	3½"
5	2' 11"	3' 9"	3' 9"	2' 2¼"	3' 0¼"	1' 3"	2' 1"	1' 4¼"	2' 2¼"	1' 4¼"	11¼"	10"	7½"	4⅜"
6	3' 6"	4' 6"	4' 6"	2' 7½"	3' 7½"	1' 6"	2' 6"	1' 7½"	2' 7½"	1' 7½"	1' 1½"	1' 0"	9"	5¼"
7	4' 1"	5' 3"	5' 3"	3' 0¾"	4' 2¾"	1' 9"	2' 11"	1' 10¾"	3' 0¾"	1' 10¾"	1' 3¾"	1' 2"	10½"	6⅛"
8	4' 8"	6' 0"	6' 0"	3' 6"	4' 10"	2' 0"	3' 4"	2' 2"	3' 6"	2' 2"	1' 6"	1' 4"	1' 0"	7"
9	5' 3"	6' 9"	6' 9"	3' 11¼"	5' 5¼"	2' 3"	3' 9"	2' 5¼"	3' 11¼"	2' 5¼"	1' 8¼"	1' 6"	1' 1½"	7⅞"
10	5' 10"	7' 6"	7' 6"	4' 4½"	6' 0½"	2' 6"	4' 2"	2' 8½"	4' 4½"	2' 8½"	1' 10½"	1' 8"	1' 3"	8¾"
11	6' 5"	8' 3"	8' 3"	4' 9¾"	6' 7¾"	2' 9"	4' 7"	2' 11¾"	4' 9¾"	2' 11¾"	2' 0¾"	1' 10"	1' 4½"	9⅝"
12	7' 0"	9' 0"	9' 0"	5' 3"	7' 3"	3' 0"	5' 0"	3' 3"	5' 3"	3' 3"	2' 3"	2' 0"	1' 6"	10½"
13	7' 7"	9' 9"	9' 9"	5' 8¼"	7' 10¼"	3' 3"	5' 5"	3' 6¼"	5' 8¼"	3' 6¼"	2' 5¼"	2' 2"	1' 7½"	11⅜"
14	8' 2"	10' 6"	10' 6"	6' 1½"	8' 5½"	3' 6"	5' 10"	3' 9½"	6' 1½"	3' 9½"	2' 7½"	2' 4"	1' 9"	1' 0¼"
15	8' 9"	11' 3"	11' 3"	6' 6¾"	9' 0¾"	3' 9"	6' 3"	4' 0¾"	6' 6¾"	4' 0¾"	2' 9¾"	2' 6"	1' 10½"	1' 1⅛"
16	9' 4"	12' 0"	12' 0"	7' 0"	9' 8"	4' 0"	6' 8"	4' 4"	7' 0"	4' 4"	3' 0"	2' 8"	2' 0"	1' 2"
17	9' 11"	12' 9"	12' 9"	7' 5¼"	10' 3¼"	4' 3"	7' 1"	4' 7¼"	7' 5¼"	4' 7¼"	3' 2¼"	2' 10"	2' 1½"	1' 2⅞"
18	10' 6"	13' 6"	13' 6"	7' 10½"	10' 10½"	4' 6"	7' 6"	4' 10½"	7' 10½"	4' 10½"	3' 4½"	3' 0"	2' 3"	1' 3¾"
19	11' 1"	14' 3"	14' 3"	8' 3¾"	11' 5¾"	4' 9"	7' 11"	5' 1¾"	8' 3¾"	5' 1¾"	3' 6¾"	3' 2"	2' 4½"	1' 4⅝"
20	11' 8"	15' 0"	15' 0"	8' 9"	12' 1"	5' 0"	8' 4"	5' 5"	8' 9"	5' 5"	3' 9"	3' 4"	2' 6"	1' 5½"
21	12' 3"	15' 9"	15' 9"	9' 2¼"	12' 8¼"	5' 3"	8' 9"	5' 8¼"	9' 2¼	5' 8¼"	3' 11¼"	3' 6"	2' 7½"	1' 6⅜"
22	12' 10"	16' 6"	16' 6"	9' 7½"	13' 3½"	5' 6"	9' 2"	5' 11½"	9' 7½"	5' 11½"	4' 1½"	3' 8"	2' 9"	1' 7¼"
23	13' 5"	17' 3"	17' 3"	10' 0¾"	13' 10¾"	5' 9"	9' 7"	6' 2¾"	10' 0¾"	6' 2¾"	4' 3¾"	3' 10"	2' 10½"	1' 8⅛"
24	14' 0"	18' 0"	18' 0"	10' 6"	14' 6"	6' 0"	10' 0"	6' 6"	10' 6"	6' 6"	4' 6"	4' 0"	3' 0"	1' 9"
25	14' 7"	18' 9"	18' 9"	11' 1¼"	15' 1¼"	6' 3"	10' 5"	6' 9¼"	10' 11¼"	6' 9¼"	4' 8¼"	4' 2"	3' 1½"	1' 9⅞"
26	15' 2"	19' 6"	19' 6"	11' 4½"	15' 8½"	6' 6"	10' 10"	7' 0½"	11' 4½"	7' 0½"	4' 10½"	4' 4"	3' 3"	1' 10¾"
27	15' 9"	20' 3"	20' 3"	11' 9¾"	16' 3¾"	6' 9"	11' 3"	7' 3¾"	11' 9¾"	7' 3¾"	5' 0¾"	4' 6"	3' 4½"	1' 11⅝"
28	16' 4"	21' 0"	21' 0"	12' 3"	16' 11"	7' 0"	11' 8"	7' 7"	12' 3"	7' 7"	5' 3"	4' 8"	3' 6"	2' 0½"
29	16' 11"	21' 9"	21' 9"	12' 8¼"	17' 6¼"	7' 3"	12' 1"	7' 10¼"	12' 8¼"	7' 10¼"	5' 5¼"	4' 10"	3' 7½"	2' 1⅜"
30	17' 6"	22' 6"	22' 6"	13' 1½"	18' 1½"	7' 6"	12' 6"	8' 1½"	13' 1½"	8' 1½"	5' 7½"	5' 0"	3' 9"	2' 2¼"
31	18' 1"	23' 3"	23' 3"	13' 6¾"	18' 8¾"	7' 9"	12' 11"	8' 4¾"	13' 6¾"	8' 4¾"	5' 9¾"	5' 2"	3' 10½"	2' 3⅛"
32	18' 8"	24' 0"	24' 0"	14' 0"	19' 4"	8' 0"	13' 4"	8' 8"	14' 0"	8' 8"	6' 0"	5' 4"	4' 0"	2' 4"
33	19' 3"	24' 9"	24' 9"	14' 5¼"	19' 11¼"	8' 3"	13' 9"	8' 11¼"	14' 5¼"	8' 11¼"	6' 2¼"	5' 6"	4' 1½"	2' 4⅞"
34	19' 10"	25' 6"	25' 6"	14' 10½"	20' 6½"	8' 6"	14' 2"	9' 2½"	14' 10½"	9' 2½"	6' 4½"	5' 8"	4' 3"	2' 5¾"
35	20' 5"	26' 3"	26' 3"	15' 3¾"	21' 1¾"	8' 9"	14' 7"	9' 5¾'	15' 3¾"	9' 5¾"	6' 6¾"	5' 10"	4' 4½"	2' 6⅝

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
36	21′ 0″	27′ 0″	27′ 0″	15′ 9″	21′ 9″	9′ 0″	15′ 0″	9′ 9″	15′ 9″	9′ 9″	6′ 9″	6′ 0″	4′ 6″	2′ 7½″
37	21′ 7″	27′ 9″	27′ 9″	16′ 2¼″	22′ 4¼″	9′ 3″	15′ 5″	10′ 0¼″	16′ 2¼″	10′ 0¼″	6′ 11¼″	6′ 2″	4′ 7½″	2′ 8⅜″
38	22′ 2″	28′ 6″	28′ 6″	16′ 7½″	22′ 11½″	9′ 6″	15′ 10″	10′ 3½″	16′ 7½″	10′ 3½″	7′ 1½″	6′ 4″	4′ 9″	2′ 9¼″
39	22′ 9″	29′ 3″	29′ 3″	17′ 0¾″	23′ 6¾″	9′ 9″	16′ 3″	10′ 6¾″	17′ 0¾″	10′ 6¾″	7′ 3¾″	6′ 6″	4′ 10½″	2′ 10⅛″
40	23′ 4″	30′ 0″	30′ 0″	17′ 6″	24′ 2″	10′ 0″	16′ 8″	10′ 10″	17′ 6″	10′ 10″	7′ 6″	6′ 8″	5′ 0″	2′ 11″
41	23′ 11″	30′ 9″	30′ 9″	17′ 11¼″	24′ 9¼″	10′ 3″	17′ 1″	11′ 1¼″	17′ 11¼″	11′ 1¼″	7′ 8¼″	6′ 10″	5′ 1½″	2′ 11⅞″
42	24′ 6″	31′ 6″	31′ 6″	18′ 4½″	25′ 4½″	10′ 6″	17′ 6″	11′ 4½″	18′ 4½″	11′ 4½″	7′ 10½″	7′ 0″	5′ 3″	3′ 0¾″
43	25′ 1″	32′ 3″	32′ 3″	18′ 9¾″	25′ 11¾″	10′ 9″	17′ 11″	11′ 7¾″	18′ 9¾″	11′ 7¾″	8′ 0¾″	7′ 2″	5′ 4½″	3′ 1⅝″
44	25′ 8″	33′ 0″	33′ 0″	19′ 3″	26′ 7″	11′ 0″	18′ 4″	11′ 11″	19′ 3″	11′ 11″	8′ 3″	7′ 4″	5′ 6″	3′ 2½″
45	26′ 3″	33′ 9″	33′ 9″	19′ 8¼	27′ 2¼″	11′ 3″	18′ 9″	12′ 2¼″	19′ 8¼″	12′ 2¼″	8′ 5¼″	7′ 6″	5′ 7½″	3′ 3⅜″
46	26′ 10″	34′ 6″	34′ 6″	20′ 1½″	27′ 9½″	11′ 6″	19′ 2″	12′ 5½″	20′ 1½″	12′ 5½″	8′ 7½″	7′ 8″	5′ 9″	3′ 4¼″
47	27′ 5″	35′ 3″	35′ 3″	20′ 6¾″	28′ 4¾″	11′ 9″	19′ 7″	12′ 8¾″	20′ 6¾″	12′ 8⅜″	8′ 9¾″	7′ 10″	5′ 10½″	3′ 5⅛″
48	28′ 0″	36′ 0″	36′ 0″	21′ 0″	29′ 0″	12′ 0″	20′ 0″	13′ 0″	21′ 0″	13′ 0″	9′ 0″	8′ 0″	6′ 0″	3′ 6″
49	28′ 7″	36′ 9″	36′ 9″	21′ 5¼″	29′ 7¼″	12′ 3″	20′ 5″	13′ 3¼″	21′ 5¼″	13′ 3¼″	9′ 2¼″	8′ 2″	6′ 1½″	3′ 6⅞″
50	29′ 2″	37′ 6″	37′ 6″	21′ 10½″	30′ 2½″	12′ 6″	20′ 10″	13′ 6½″	21′ 10½″	13′ 6½″	9′ 4½″	8′ 4″	6′ 3″	3′ 7¾″
51	29′ 9″	38′ 3″	38′ 3″	22′ 3¾″	30′ 9¾″	12′ 9″	21′ 3″	13′ 9¾″	22′ 3¾″	13′ 9¾″	9′ 6¾″	8′ 6″	6′ 4½″	3′ 8⅝″
52	30′ 4″	39′ 0″	39′ 0″	22′ 9″	31′ 5″	13′ 0″	21′ 8″	14′ 1″	22′ 9″	14′ 1″	9′ 9″	8′ 8″	6′ 6″	3′ 9½″
53	30′ 11″	39′ 9″	39′ 9″	23′ 2¼″	32′ 0¼″	13′ 3″	22′ 1″	14′ 4¼″	23′ 2¼″	14′ 4¼″	9′ 11¼″	8′ 10″	6′ 7½″	3′ 10⅜″
54	31′ 6″	40′ 6″	40′ 6″	23′ 7½″	32′ 7½″	13′ 6″	22′ 6″	14′ 7½″	23′ 7½″	14′ 7½″	10′ 1½″	9′ 0″	6′ 9″	3′ 11¼″
55	32′ 1″	41′ 3″	41′ 3″	24′ 0¾″	33′ 2¾″	13′ 9″	22′ 11″	14′ 10¾″	24′ 0¾″	14′ 10¾″	10′ 3¾″	9′ 2″	6′ 10½″	4′ 0⅛″
56	32′ 8″	42′ 0″	42′ 0″	24′ 6″	33′ 10″	14′ 0″	23′ 4″	15′ 2″	24′ 6″	15′ 2″	10′ 6″	9′ 4″	7′ 0″	4′ 1″
57	33′ 3″	42′ 9″	42′ 9″	24′ 11¼″	34′ 5¼″	14′ 3″	23′ 9″	15′ 5¼″	24′ 11¼″	15′ 5¼″	10′ 8¼″	9′ 6″	7′ 1½″	4′ 1⅞″
58	33′ 10″	43′ 6″	43′ 6″	25′ 4½″	35′ 0½″	14′ 6″	24′ 2″	15′ 8½″	25′ 4½″	15′ 8½″	10′ 10½″	9′ 8″	7′ 3″	4′ 2¾
59	34′ 5″	44′ 3″	44′ 3″	25′ 9¾″	35′ 7¾″	14′ 9″	24′ 7″	15′ 11¾″	25′ 9¾″	15′ 11¾″	11′ 0¾″	9′ 10″	7′ 4½″	4′ 3⅝″
60	35′ 0″	45′ 0″	45′ 0″	26′ 3″	36′ 3″	15′ 0″	25′ 0″	16′ 3″	26′ 3″	16′ 3″	11′ 3″	10′ 0″	7′ 6″	4′ 4½″
61	35′ 7″	45′ 9″	45′ 9″	26′ 8¼″	36′ 10¼″	15′ 3″	25′ 5″	16′ 6¼″	26′ 8¼″	16′ 6¼″	11′ 5¼″	10′ 2″	7′ 7½″	4′ 5⅜″
62	36′ 2″	46′ 6″	46′ 6″	27′ 1½″	37′ 5½″	15′ 6″	25′ 10″	16′ 9½″	27′ 1½″	16′ 9½″	11′ 7½″	10′ 4″	7′ 9″	4′ 6¼″
63	36′ 9″	47′ 3″	47′ 3″	27′ 6¾″	38′ 0¾″	15′ 9″	26′ 3″	17′ 0¾″	27′ 6¾″	17′ 0¾″	11′ 9¾″	10′ 6″	7′ 10½″	4′ 7⅛″
64	37′ 4″	48′ 0″	48′ 0″	28′ 0″	38′ 8″	16′ 0″	26′ 8″	17′ 4″	28′ 0″	17′ 4″	12′ 0″	10′ 8″	8′ 0″	4′ 8″
65	37′ 11″	48′ 9″	48′ 9″	28′ 5¼″	39′ 3¼″	16′ 3″	27′ 1″	17′ 7¼″	28′ 5¼″	17′ 7¼″	12′ 2¼″	10′ 10″	8′ 1½″	4′ 8⅞″
66	38′ 6″	49′ 6″	49′ 6″	28′ 10½″	39′ 10½″	16′ 6″	27′ 6″	17′ 10½″	28′ 10½″	17′ 10½″	12′ 4½	11′ 0″	8′ 3″	4′ 9¾″
67	39′ 1″	50′ 3″	50′ 3″	29′ 3¾″	40′ 5¾″	16′ 9″	27′ 11″	18′ 1¾″	29′ 3¾″	18′ 1¾″	12′ 6¾″	11′ 2″	8′ 4½″	4′ 10⅝″
68	39′ 8″	51′ 0″	51′ 0″	29′ 9″	41′ 1″	17′ 0″	28′ 4″	18′ 5″	29′ 9″	18′ 5″	12′ 9″	11′ 4″	8′ 6″	4′ 11½″
69	40′ 3″	51′ 9″	51′ 9″	30′ 2¼″	41′ 8¼″	17′ 3″	28′ 9″	18′ 8¼″	30′ 2¼″	18′ 8¼″	12′ 11¼″	11′ 6″	8′ 7½″	5′ 0⅜″
70	40′ 10″	52′ 6″	52′ 6″	30′ 7½″	42′ 3½″	17′ 6″	29′ 2″	18′ 11½″	30′ 7½″	18′ 11½″	13′ 1½″	11′ 8″	8′ 9″	5′ 1¼″
71	41′ 5″	53′ 3″	53′ 3″	31′ 0¾″	42′ 10¾″	17′ 9″	29′ 7″	19′ 2¾″	31′ 0¾″	19′ 2¾″	13′ 3¾″	11′ 10″	8′ 10½″	5′ 2⅛″
72	42′ 0″	54′ 0″	54′ 0″	31′ 6″	43′ 6″	18′ 0″	30′ 0″	19′ 6″	31′ 6″	19′ 6″	13′ 6″	12′ 0″	9′ 0″	5′ 3″
73	42′ 7″	54′ 9″	54′ 9″	31′ 11¼″	44′ 1¼″	18′ 3″	30′ 5″	19′ 9¼″	31′ 11¼″	19′ 9¼″	13′ 8¼″	12′ 2″	9′ 1½″	5′ 3⅞″
74	43′ 2″	55′ 6″	55′ 6″	32′ 4½″	44′ 8½″	18′ 6″	30′ 10″	20′ 0½″	32′ 4½″	20′ 0½″	13′ 10½″	12′ 4″	9′ 3″	5′ 4¾″
75	43′ 9″	56′ 3″	56′ 3″	32′ 9¾	45′ 3¾″	18′ 9″	31′ 3″	20′ 3¾″	32′ 9¾″	20′ 3¾″	14′ 0¾″	12′ 6″	9′ 4½″	5′ 5⅝″
76	44′ 4″	57′ 0″	57′ 0″	33′ 3″	45′ 11″	19′ 0″	31′ 8″	20′ 7″	33′ 3″	20′ 7″	14′ 3″	12′ 8″	9′ 6″	5′ 6½″

NAILS REQUIRED PER 1000 FT. B. M. LUMBER

Size common nail	Number required (pounds)	Size finishing nail	Number required (pounds)	Size plank	Spacing of joists or purlins (inches)
8d	33	8d	18	1 × 6	12
	21		12		18
	16		9		24
16d	23	20d	35	2 × 6	24
	9½		14		60
	8		12		72
	6½		10		84
	6		9		96
	5½		8		108
50d	26	60d	31	3 × 10	36
	22½		26½		42
	19½		23½		48
	15½		18½		60
	13		15½		72
	11		13		84
	9¾		11½		96
	9		10½		108
	8		9		120

The values given in foregoing nail table are for average lengths of wood, double nailed at the ends and single nailed at intermediate points. Where end joints occur, both abutting ends are usually double nailed, and for that reason, the number of nails for a given work will vary with lengths of the boards used. When large surfaces are estimated, it is often worth while to develop the actual number of nails which can be resolved into pounds by using the following weights:

Size nail	Extra per cwt.	Length (inches)	Gage	Approx. number of nails in 1 lb.
60d.	Base	6	2	11
50	Base	5½	3	14
40	Base	5	4	18
30	Base	4½	5	24
20	Base	4	6	31
16	0.05	3½	8	49
12	0.05	3¼	9	63
10	0.05	3	9	69
9	0.10	2¾	10¼	96
8	0.10	2½	10¼	106
7	0.20	2¼	11½	161
6	0.20	2	11½	181
5	0.30	1¾	12½	271
4	0.30	1½	12½	316
3	0.45	1¼	14	568
2	0.70	1	15	876

It is convenient to group all nails and other hardware in the estimate, omitting these at the time the carpentry is listed.

Wood nailers are frequently used on steel members for fastening corrugated iron, wood roofs, millwork, etc. For ordinary roof decks, 2 × 4 or 2 × 6-in. nailers are commonly used with a 3 × 4 or 3 × 6 wherever ends of roof boards butt together and double nailing occurs. ½-in. carriage bolts are usually estimated on 18 to 36-in. centers.

Material and labor are figured by the thousand feet board measure. The main feature in determining the labor allowance may be the possibility of bolting the nailer before the steelwork is erected. Nailers attached to steel members after erection may cost from 50 to 150 % more.

Roof Decking.—The cost of applying roof planking like all other roofing operations depends mostly upon the slope of the roof and the extent to which the roof surface is broken up. On a flat roof where the carpenter need

take no precautions against sliding, the work is carried on at a faster pace. Height of roof will also influence the cost. If the roof is too high to permit workman on the ground to hand the boards up to the men above, costs of hoisting are included. For factory buildings it is more a case of hoist or no hoist, as there is no appreciable difference in the cost for raising lumber 25 or 65 ft. The unit cost may be estimated as follows:

1 M	2 × 6 dressed and matched, LLYP	$50 00
12 lb.,	16d nails at 6c	0.72
	Labor unloading lumber	1 00
	Labor laying	15.00
		$66.72

Temporary end or side framing of studs and sheathing, or studs and siding, is often estimated for steel factory buildings when the owner anticipates further expansion. The material (studding and surfacing) is generally listed and estimated as two separate items, resolved into feet board measure, priced and extended by the thousand. To arrive at the labor cost of this kind of framing, some estimators apply a price per square foot covering both the siding and studding costs. The labor cost for studding usually runs more, however, and by separate listing more accurate units are employed.

Interior Trim.—The costs of the various moldings used for interior trimming unlike most branches of carpentry, are frequently based on a price per lineal foot, both the material and labor costs being made up on this basis. The material includes the gross size of the section planed plus the cost for running the board through the mill. Plain sections cost about the same as fancy ones, providing there is the same number of machining operations. The labor costs include the use of finishing nails set into the wood so that the holes may later be puttied over by the painter.

16. Painting.—Painting is estimated by units of area, sometimes 1 sq. ft., 1 sq. yd., or 1 square. The unit—1 square—seems most practical because, if anything, it is easier to develop a price per 100 sq. ft. than a price for 1 sq. ft. Furthermore, to maintain the same accuracy, a unit per square foot must be carried into several more decimal places, and this seems like unnecessary detail. In arriving at the number of squares, the take-off includes the gross areas to be covered. Like all other operations, surfaces with varying unit costs are taken off separately so that the correct unit price may be speedily approximated for the several items, each of which includes only one class of work. Each list bears a caption fully describing the material and the number of coats the surface is to receive. When listing the painting of glazed doors and windows, no deduction is made for the glass. The extra cost of painting the narrow striping balances the saving of material. It is well, however, to note the area of this kind of surface in the event the exact amount of paint will have to be determined later. The labor conditions are best derived by reference to the drawings.

VALUES FOR ONE GALLON OF MIXED PAINTS

Kind of paint	Pounds of pigment	Volume of liquid element (gallons)	Surface covering value				
			Metal	Smooth wood	Plaster	Brick	
Lead and linseed oil	17	¾	300	250	200	170	First or second coat
Zinc and linseed oil	12	¾	400	330	270	220	First or second coat
Hard oil or varnish	..	..	480	400	320	270	First coat only
Hard oil or varnish	..	..	...	500	400	350	Second coat only
Glue size and water	½	¾	...	400	300	250	First coat only
Cold water paint..	5	¾	250	250	225	200	First coat only

The increased covering or spreading value of the zinc paint does not represent any economy over the use of lead paint, as the zinc will not usually cover as effectively as the lead. Up to 10% of dryer may be used to force the chemical action of the drying and lessen the drying time of the first coat, but dryers are seldom estimated as an ingredient of the last two coats as it is generally known that the wearing quality of paint is impaired proportionately with the amount of dryer added. Similarly, glue size as a first coat is estimated only for the cheaper grades of work. The cost of glue size is about 5% of that of good paint but it will not adhere nearly as well as a first coat of thin paint. The unit cost of painting for common classes of work is usually understood to include scaffold labor. In only rare instances does a painter do any work for which no ladders and staging are necessary.

17. Composition Roof Coverings.—Roofing is generally estimated by the square—that is, a unit of 100 sq. ft. The roof surfaces are listed in the estimate allowing about 1 ft. at

parapets, or more when specified, and the area resolved into squares. As the average general contractor usually purchases roofing in place from the roofers, quotations are generally used for pricing the estimate. The unit price as quoted by the roofer having a specified type and weight of roofing in mind, would depend on the pitch of roof, height, number of separate roofs into which the area may be divided, and the construction of the roof deck. A roof is generally termed steep or flat depending upon whether roof ladders need be used. The division occurs in the neighborhood of ¼ pitch.

18. General Field Expenses.—After all of the building operations have been included in the estimate, a summary is made of the costs for conducting all work not a part of any specific installation. These generals may be listed separately or grouped in the following manner with the total carried over into the right-hand column as shown on sample estimate in Art. 2. Assuming a factory building costing about $800,000, these items will appear approximately as follows:

Amount brought forward		$698,134.00
Clearing rubbish from premises	$1,000.00	
Freight on 6 to 10 carloads equipment per tool list	400 00	
Railroad fares	400.00	
Coal, 300 tons at $6	1,800.00	
Temporary sheds	700 00	
Office stationery, stamps, etc.	100 00	
Telegraph and telephone expense	500 00	
Superintendent, 9 months at 350	3,150 00	
General foreman, 9 months at 250	2,250 00	
Civil engineer, 8 months at 200	1,600 00	
Timekeeper, 9 months at 160	1,440 00	
Car tracer	800 00	
Two watchmen, 9 months at 100	1,800 00	
*Insurance (Workmans Compensation and Liability) 10% of ⅓ of $800,000	26,667 00	42,607.00
		$740,741.00
Overheads (say 8%)		59,259.00
Total cost		$800,000.00

* 10% is the estimated rate of insurance for factory structures. Rates vary in different localities. ⅓ is the estimated proportion of labor to the total cost of the building—in other words, the estimated payroll expenditure.

Adding field overheads to the other costs appearing in the estimate gives a total on which the general office and contracting overheads can be based. The percentage used to determine this general office overhead depends entirely upon what proportion of the organization is contained in the general office. By adding this percentage in the estimate, the net cost of the construction is established and only the allowance for profit is needed to arrive at the bidding price. Naturally the above outline will not serve for all conditions affecting estimates. Often an organization uses a smaller profit factor on sub-bids than on the work to be executed by its own forces, and in that event the estimator should use a separate column for sub-bids or have other ready means for determining at once the total amount of the work to be sublet.

SECTION 2

ESTIMATING CONCRETE BUILDINGS[1]

By Clayton W. Mayers

Making an estimate for a reinforced concrete building involves much more labor than is required in the preparation of estimates for buildings constructed of structural steel, brick, wood, or a combination of these materials. This becomes obvious when we consider that a reinforced concrete beam is composed of a certain amount of cement, sand, crushed stone, water, reinforcement, formwork, and labor, while a steel I-beam in place in a building represents, insofar as we are concerned, only a certain amount of structural steel and labor.

In order to estimate the cost of a reinforced concrete beam, column, floor slab or wall, it is necessary to determine the amount of concrete, steel reinforcement, formwork, and labor involved and to these amounts affix proper unit prices. In arriving at proper unit prices, it is necessary to still further subdivide the amount of concrete into its constituent parts of cement, sand, and crushed stone. The amount of lumber necessary to properly form the concrete must be determined before a correct unit price for formwork can be decided upon. The necessary amount of plant equipment and labor must be carefully considered and the cost determined before the estimate is complete. Compare with this the process of estimating the cost of a steel member in a building, which consists of so many pounds of steel and so much labor, and we readily appreciate that to estimate properly all the structural members of a reinforced concrete building requires much more detail work than is required in estimating most other types of building construction.

1. Systematic Procedure Advisable.—In estimating the cost of a reinforced concrete building it is necessary to make a complete list of all materials and labor, arranging this list in a convenient form, using methods which permit this to be done with the least amount of labor. In making this list it is necessary to consider every structural member in the building from the footings to the roof slab. The quantities are determined by carefully "scaling" the plans of the proposed building. These estimated quantities are then priced out and the sum of the extended totals to which have been added the cost of superintendence, liability insurance, profit, and other items common to all building operations will, if correctly done, represent to a close degree the final cost of the work.

2. Estimating Quantities.—Making a "quantity survey" of the plans, or "scaling" the plans as it is commonly called, is the first step in preparing an estimate. In order to perform the work rapidly and with the least possible chance for error, properly ruled stationery is very essential. Paper ($8\frac{1}{2} \times 11$ in.) ruled similar to the copy shown below has been found of excellent design and its use is recommended.

Col. No. 1	Col. No. 2	Col. No. 3	Col. No. 4	Col. No. 5	Col. No. 6	Col. No. 7	Col. No. 8	Col. No. 9
"Description"	"Times"	"Length"	"Width"	"height"	"Quantity"	"Summary"	"Unit price"	"Total"

Column No. 1 is the "description" column. It is used to note briefly the location and character of the work being scaled in order that future identification may be easily made. Column No. 2 is the "times" column. In this column should be noted the number of pieces or duplicate members which are being scaled from the plans as exactly alike. If no duplicate pieces are shown on the drawing, this column is not used and it is understood that but one member or unit is to be estimated. Column No. 3 is the "first dimension" column, or "length" column. Column No. 4 is the "second dimension," or "width" column. Column No. 5 is the "third dimension," or "height" column. Column No. 6 is the "quantity" column and should contain the extended quantity only. Column No. 7 is the "summary" column in which the total of the "quantity" column is shown reduced to the unit

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of measure generally accepted as the standard measure ready for pricing out, as cubic yards of concrete, tons of steel reinforcement, etc. Column No. 8 is for the "unit price." Column No. 9 is the "total" column, for the product obtained by multiplying the summarized quantity by the unit price. This product is carried out in even dollars.

On account of the comparatively large amount of detail work involved in estimating the cost of reinforced concrete construction, it is quite important that a definite system or "order of scaling" be laid out and carefully followed. If this is done, the work of "scaling the plans" is greatly simplified and the liability of error is reduced to a minimum. In preparing the list or "order of scaling," the items to be scaled should be considered in the order of actual job construction with one or two exceptions mentioned later on in this chapter.

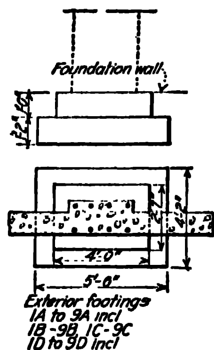


Fig. 1

2a. Area and Cube.—At the beginning of each estimate for a building should be noted the square foot area of the floors of the building and the cubical contents of the structure. This is done in order that the estimator may, with practice, learn to judge the cost of the work quite closely on a square and cube foot basis before the estimate is begun. Practice of this kind, checked up after the estimate is completed, will be very helpful in developing the estimator's judgment. In considering the area, the floors (including basements) are measured and the dimensions are taken "out to out." For instance, the areas of a building two stories high, 160 ft. long, and 60 ft. wide should appear on the estimate sheet as follows: 2 × 160 × 60 = 19,200 sq. ft. The cubical contents of the building should be figured from the same length and width dimensions and the total height from the bottom of the basement floor to the top of the roof slab. The cubical contents or "cube" as it is commonly called, would appear as follows: 160 × 60 × 23⅔ = 227,200 cu. ft.

2b. Concrete—*Exterior and Interior Footings.*—In "scaling" the quantities of a concrete footing it is necessary to first determine the amount of concrete in the footing by tabulating in the proper column of the estimate sheet the dimensions of the footing. For example, Fig. 1 represents one of twenty-two typical exterior column footings for a reinforced concrete building. First describe the footings in column No. 1 as follows: footing No. 1A to 9A inclusive, 1B and 9B, 1C and 9C, and 1D to 9D inclusive. Next, in column No. 2 note the number of footings which are alike (in this case 22). In the "length" column, note the length of the lower block (5½ ft.), following with the width and height dimensions (4⅙ ft. and 1⅙ ft., respectively). Thus the concrete contained in the lower blocks of these 22 footings is tabulated as 22 × 5½ × 4⅙ × 1⅙. On the line below should be tabulated the upper block of the footings which will appear 22 × 4 × 2 7/12 × 1. The scaling of the quantities in the interior footings (Fig. 2) is handled in the same way and, when properly tabulated on the estimate sheet, appears as follows:

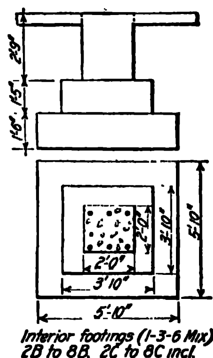


Fig. 2.

Concrete-Exterior footings (1-3-6) Mix)								
1A to 9A incl								
1B and 9B	22	× 5½	× 4⅙	× 1⅙	=			
1C and 9C	22	× 4	× 2 7/12	× 1	=		} =	Cy.
1D to 9D incl								
Concrete-Interior footings (1-3-6 Mix)								
2B to 8B incl	14	× 5⅚	× 5⅚	× 1[illegible]	=			
2C to 8C incl	14	× 3[illegible]	× 3[illegible]	× 1[illegible]	=			
	14	× 2	× 2	× 2[illegible]	=			

This completes the "scaling" of the concrete in the footings. It will not be necessary to refer to the plans again in order to get the form quantities in connection with these footings. This will be explained later on under "Formwork."

It will be noted that fractions are used instead of inches or decimal parts of a foot. To use inches makes extension of totals difficult and the tabulation unwieldy. To use decimals is inviting error as the decimal point is very likely to be misplaced or omitted. Years of practice have proved that the only safe method is to use fractions of a foot when inches are implied and no fraction to be smaller than one-twelfth (1/12). Thus: 3 ft. 5 in. = 3 5/12 ft., 6 ft. 9 in. = 6 3/4 ft., and 8 ft. 10 in. = 8 5/6 ft. Where half inches are involved in concrete work (except in the thickness of floors), the fraction should be equivalent to the next higher even inches. For example: 6 ft. 5 1/2 in. = 6 1/2 ft. and 7 ft. 2 1/2 in. = 7 1/4 ft. This ruling can be safely followed without danger of gross error with the exception of floor thickness which will be discussed under "Floor Slabs."

As all handbooks show the weights of steel bars in decimal parts of a pound, it will be necessary to use decimals in computing the tonnage of steel reinforcement.

The slide rule will be found of great value in extending the quantities and its intelligent use will result in both speed and accuracy. All arithmetical computations should be checked by a second person before the estimate is submitted.

Certain abbreviations are used to simplify the scaling of reinforced concrete. In order to remove as far as possible the liability of error, it has been found that by reversing the order of the letters in some of the abbreviations that fewer mistakes are made due to carelessly made letters placed next to figures being mistaken for figures themselves. The following abbreviations have been used extensively and are recommended; c.y. = cubic yards, s.y. = square yards, f.c. = cubic feet, s.f. = square feet, f l. = linear feet, sqs. = squares (100 sq. ft.), # = when placed first stands for the number of units # = when placed after stands for pounds, Ddt. = deduct.

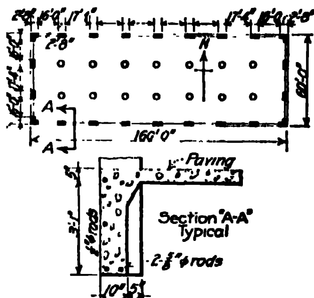


Fig. 3

Foundation Walls.—Under this heading, generally speaking, should be included all concrete walls below grade. In scaling such walls the quantity scaled should include all concrete above grade which can be correctly classed as a part of the foundation wall. For example, a cellar wall may extend a foot or more above grade before reaching the level of the first floor, yet the part above grade will be classed as foundation wall along with the part of this wall which is built below the grade level. It is the usual practice to include under the heading of "Foundation Walls" all the concrete walls which are below the level of the first floor and includes area walls, pit walls, etc. Fig. 3 represents a cross section and plan of the foundation wall extending around a reinforced concrete building having a length of 160 ft. and a width of 60 ft. In scaling the quantity of concrete in this foundation wall the sections or pieces of wall should be considered by elevation as follows:

Concrete-Foundation walls								
South elev.	160	x	5/6	x	3 1/12	=		
splayed top	[160-(9x2 2/3)]	x	1/4 av	x	5/6	=		
pilasters	7 x 2 2/3	x	5/12	x	3 1/12	=		
East elev.	(60-1 2/3)	x	5/6	x	3 1/12	=		
splayed top	[60-(4x2 2/3)]	x	1/4 av	x	5/6	=		
pilasters	2 x 2 2/3	x	5/12	x	3 1/12	=		
North elev.	160	x	5/6	x	3 1/12	=	} =	c.y.
splayed top	[160-(9x2 2/3)]	x	1/4 av	x	5/6	=		
pilasters	7 x 2 2/3	x	5/12	x	3 1/12	=		
West elev.	(60-1 2/3)	x	5/6	x	3 1/12	=		
splayed top	[60-(4x2 2/3)]	x	1/4 av	x	5/6	=		
pilasters	2 x 2 2/3	x	5/12	x	3 1/12	=		
Corner piers	4x[(1[illegible]x1[illegible])-([illegible]x1[illegible])]			x	3 1/12	=		

It will be noted that in scaling the concrete foundation wall shown above, the wall on the side or south elevation is scaled for the full length of the elevation. The quantity of concrete in the splayed part is added as part of the foundation wall. The concrete in the 7 piers or pilasters is then added, always considering the dimensions in the order of length, width, and height. Next the east or end wall is scaled (progressing anti-clockwise). In the case of the ends, in order to avoid doubling the amount of material in the corners, the inside dimension is scaled instead of the outside "overall" dimension. This dimension should be set down in the length column to read (60–1 2/3). The concrete in the two piers or pilasters is next added. The north wall is scaled similar to the south, and the west similar to the east. The concrete in the 4 corner piers is then added and the scaling for the foundation wall is complete.

Exterior and Interior Columns.—Fig. 4 represents a part cross section showing the typical exterior columns of a building 160 ft. long and 60 ft. wide. Assuming these typical columns to be

spaced 20 ft. apart, there will be 18 such columns in the building and 4 corner columns. The scaling of the quantity of concrete in these columns will appear as follows:

Concrete-Exterior Cols. (1-2-4)										
1st story										
2A to 8A incl.	18	x	2⅔	x	1¼	x	11	=		
1B, 9B, 1C, 9C.										
2D to 8D incl.										
Corner cols	4	x[(2⅔x2⅔)-(1⅓x1⅓)] x 11						=		
Mullion			1¼	x	1½	x	11	=	=	c.y.
Col. brackets	18	x	4⅓		cubic feet			=		
2nd story (1-2-4)										
Same as 1st story	18	x	2⅔	x	1¼	x	11½	=		
Corner cols	4	x[(2⅔x2⅔)-(1⅓x1⅓)] 11½						=		
Mullion			1¼	x	1½	x	10	=		
Col. brackets	18	x	4⅓		cubic feet			=		

Following through this scaling we have in the "times" column the number 18, which denotes the number of typical exterior columns in each story. In the next three columns of the estimate sheet are found the length, width, and height respectively of the columns being scaled. Each of the four corner columns has both exterior faces of the same dimension, but the inside corner is notched out. This complicates the expression representing the cross-sectional area of this corner column, which is set down in the "length" and "width" columns of the estimating sheet. This expression consists of two parts. The first part represents a rectangular column and the second part represents the area of the notched portion of the column which is to be deducted from the larger area. Corner columns or irregular columns should always be scaled in this manner. The second story columns are scaled similar to the first story columns above discussed. As the concrete brackets only remain to be scaled it is necessary to count up the number of brackets and to determine the approximate number of cubic feet of concrete in one bracket. This completes the scaling of concrete in the exterior columns.

Fig

Fig. 5.

The scaling for the interior columns is done in a similar manner, unless they happen to be round instead of square. Suppose Fig. 5 represents a typical interior first and second story column of a building in which these are 14 suse columns. The scaling for these 14 first story and 14 second story columns would appear as follows:

Concrete-Interior cols. (1-1½-3)							
1st story							
2B to 8B, 2C to 8C	14	x(20" dia)	2⅛ s.f. x 10⅔	=	=	c.y.
Col. heads	14	x	13	cubic feet	=		
2nd story (1-2-4)							
Same as 1st story	14	x(14" dia)	1 1/12 s.f. x 11⅛ avg.	=	=	c.y.
Col. heads	14	x	19	cubic feet	=		

In scaling the interior columns the second column on the estimate sheet should contain the number of identical members being scaled (14 in this case). As these interior columns are round it is not possible to use the "length" and "width" columns exactly as outlined at the beginning of this chapter. These two columns should contain

however, figures which represent the cross-sectional area of the column. It is best to do this by noting the diameter of the column, enclosing same in parenthesis. Immediately following should be noted in square feet the cross-sectional area of the column. The "height" column should contain the length of the member from floor to the level of the bottom of drop panel. Next is noted in the "times" column the number of column heads (usually the same as the number of columns) and in the "length" and "width" columns the approximate number of cubic feet of concrete in the head which is in excess of the shaft already scaled. The similar tabulation of the upper story columns completes the scaling of interior column concrete.

Floor Slabs and Roof Slab.—Scaling the quantity of concrete in floor and roof slabs is very simple. As in scaling the concrete for beams and columns, the dimensions should be taken off in the order of length, width, and height. For instance, suppose it is necessary to scale the concrete in the second floor slab and roof slab of a reinforced concrete building 160 ft. long and 60 ft. wide. The second floor slab is 7½ in. thick and the edge of the slab is set back 2 in. from line of face of building. There is a stair well opening in the slab 18¼ ft. long and 10 ft. wide. The roof slab is 6 in. thick and has no opening. The quantities of concrete would appear as follows:

Concrete—Floor slab									
2nd floor	159⅔	x	59⅔	x	15/24	=	}	=	c.y.
deduct opening	18¼	x	10	x	15/24	Ddt=			
roof slab	160	x	60	x	½	=			

It will be found in first practice that it is the natural tendency to put down the thickness of the slab in the "width" column instead of in the last or "height" column. This tendency will be quickly overcome if the estimator remembers that whether it is beam, column, or floor slab, the order of scaling dimensions of concrete should always be length, width, and height. The thickness of the slab is a very important dimension and should be accurately tabulated on the estimate sheet. If the slab thickness if 5½ in., the fraction tabulated in the "height" column should be 11/24. This is one of the very few instances which occur in scaling concrete work when fractions having denominators larger than 12 are recommended.

Drop Panels.—Drop panels, which occur over the column heads of flat slab designs should be considered as small floor or roof slabs when being scaled for estimate purposes. The quantity of concrete in the drop panels shown under the floor slab and roof slab in Fig. 5 would appear on the estimate sheet as shown below.

Concrete—Drop panels										
2nd floor	14	x	7½	x	7½	x	[illegible] av.	=	} =	c.y.
roof	14	x	7½	x	7½	x	[illegible]	=		

Wall Beams.—Under the heading "Wall Beams," must be included the curtain walls, parapet beams, and other similar structural members. In Fig. 4 is shown a typical wall beam and parapet beam in a building 160 ft. long and 60 ft. wide. The exterior columns are 20 ft. apart. The concrete in the wall beams and parapet beams will appear as follows:

Concrete—Wall beams								
2nd floor	{[(2x160)+(2x60)]-(26x2⅔)}							
	[illegible]	x	1½	x	1½	=	} =	c.y.
roof parapet	[(2x160)+(2x58⅔)]	x	⅓	x	2⅙	=		
coping projection	[(2x160)+(2x60)]	x	¼	x	7/12	=		

The expression within the braces represents the total actual length of wall beam. Within the braces we find two expressions, the first enclosed in brackets and the last in parenthesis only. The first of these represents the perimeter of the building and the second the total length of column faces which should be deducted from the perimeter in order to arrive at the actual total length of wall beam. The parapet is scaled in a similar manner but no deductions are made except for overlapping corners. It will be found that errors will be avoided if wall beams,

parapets, etc., are scaled in this manner. If the beams are considered individually, omissions of entire beams are very likely to occur and the error would easily be passed unnoticed

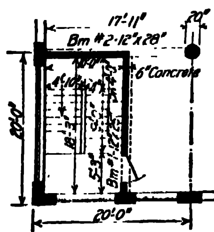


Fig. 6.

Interior Floor Beams.—Interior floor beams are usually scaled by simply noting in the "description" column the location or index number of the beam or beams. The "times" column should contain the number of identical beams, and the "length," "width," and "height" columns should be used according to rulings set forth throughout the preceding pages of this chapter. The height of a beam should always be taken exclusive of the slab thickness. Beams around stair openings should be treated in the same way except that sketches of the cross section of the beam should usually be made in the "description" column as a help in determining the form work as explained later on under "Formwork for Beams." For instance, if we have two stair well beams as shown in Fig. 6 the quantities of concrete would appear as follows:

Concrete—Interior floor beams									
2nd fl. at stairs									
Bm #1, 12"x26"	18¾	x	1	x	1⅔	=			
Same Bm #2 12"x28"	10	x	1	x	1⅔	=	} =		C.Y.
Bm #2, 12"x26"	7½	x	1	x	1⅔	=			

Partitions.—Concrete partitions are scaled in the same manner as interior concrete beams. In the "description" column should be noted the approximate location or character of the partitions and the remaining columns of the estimate sheet are to be used as hereinbefore set forth, always bearing in mind that, in this case, the thickness of the partition is the "width" or second dimension scaled. The concrete quantities appear below for the 6-in. concrete partitions shown in Fig. 6 and occurring on the first and second floors of a building having a story height of about 11 ft.

Concrete—Partitions									
around stairs, 1st	(10+18¾)	x	½	x	11	=			
deduct for door	3	x	½	x	7	Ddt =			
2nd story	(10+18¾)	x	½	x	11½	avg. =	} =		C.Y.
deduct for door	3	x	½	x	7	Ddt =			

Window Sills and Copings.—Concrete window sills and copings are scaled by the linear foot and in taking off the quantity of each, the work proceeds by elevations. For instance, in the "description" column should appear the words "south elevation" after which should appear in the "times" and "length" columns the number and length of the window sills or coping on the south elevation. The east, north, and west elevations should then be considered in turn. A cross-sectional sketch or notation as to size of sill or coping should be made in the "description" column, as a help in determining the correct unit price per linear foot when the work of pricing the estimate is to be done. The following illustrates the proper method of scaling window sills. Should concrete copings occur on top of brick parapet walls similar methods should be observed.

Concrete—Window sills (incl'g forms and reinf.)							
13"x6" Sq.	12	x	17⅝	=			
4-⅜" rods	2	x	16	=			
	2	x	6¾	=			
	1	x	8	=			
	2	x	17⅝	=	}		f.l.
	4	x	16	=			
	12	x	17⅝	=			
	4	x	16	=			
	2	x	17⅝	=			
	4	x	16	=			

Stairs and Landings.—Fig. 7 represents the flight of reinforced concrete stairs shown in Fig. 6. In order to "scale" the stairs it is necessary to count the number of nosings (18 in this case), and set the number down in the "length" column. The "width" column should contain the length of each nosing from wall to outer edge. The product of the two dimensions will give the linear feet of nosing which should be taken as the standard of measure for concrete stairs. The landings are measured by the square foot and the landing beams may be neglected, as in pricing out the cost of the landing per square foot, proper allowance is made for the extra cost of the landing beam. The thickness of the landing slab may also be

Section Through Stairs

FIG. 7.

neglected as in the case of the stairs. Concrete stairs and landings, unless of special design, may be considered in this manner without appreciable error in cost estimating. Below is given the proper scaling of the concrete stairs and landing shown in Figs. 6 and 7.

Concrete—Stairs and Landings						
stair nosings	18	x	4 5/6	=	} =	fl.
landings	10	x	4	=		
	10	x	3 1/3	=		sf

Paving.—Concrete paving is a term applied to an unreinforced concrete slab resting on earth fill, such as a basement floor or the first floor of a building where no basement is called for. In scaling the quantity of concrete in a concrete paving the same rules are observed as laid down for a concrete slab. The concrete in a piece of paving 5 in. thick and 160 ft. long by 60 ft. wide would appear on the estimate sheet as follows:

Concrete-Paving	160	x	60	x	5/12	=	c.y.

Granolithic Finish.—Scaling the quantity of granolithic finish in a building is done at this stage of the estimate because the surfaces having granolithic finish applied to them have already been scaled, and it is simply a matter of referring to previous dimensions in order to determine the quantity of granolithic finish required. For instance, if the second floor slab previously scaled is to be finished with a granolithic finish of the "laid after" type, and on the paving above an integral granolithic finish is called for, the granolithic finish dimensions would appear on the estimate sheet as follows:

Granolithic finish—(laid after)					
2nd floor	(159 2/3 - 2 2/3)	x	(59 2/3 - 2 2/3) =	} =	s.f.
deduct	10	x	18 [illegible] Ddt =		
Granolithic finish—(laid integral)					
paving	(159 2/3 - 2 2/3)	x	(59 2/3 - 2 2/3) =		s.f.

Carborundum Rubbing.—The area of the surfaces to be treated with carborumdum rubbing can be more easily determined if left until the formed surfaces have been determined. This will be taken up in another part of the chapter.

2c. Formwork.—If the foregoing rules have been carefully followed in regard to scaling concrete, the work of determining the amount of formwork necessary to mould the concrete may be very easily done with practically no further reference to the drawings, and at the same time the results are accomplished in the least possible time. In writing out the form dimensions it is necessary to refer to the concrete dimensions and copy such figures as will give the formed surfaces. As but three columns of the estimating sheet are needed in tabulating the dimensions for formwork, the second or "times" column is left blank and the remaining three columns used for this work. Very little "description" is needed in writing out formwork dimensions, since, in order to learn the character of the work formed, it is necessary only to turn back to the concrete scaling corresponding to the formed surfaces in question. Enough description should be given in the "description" column to make it easy to identify the form dimensions with the concrete scaling.

Forms for Exterior and Interior Footings.—The form dimensions for the concrete footings as scaled from Fig. 2 are shown properly written out below.

Forms-Exterior footings								
	22	x	19 1/3	x	1 1/6	=		
	22	x	13 1/3	x	1	=		
Interior footings	14	x	23 1/3	x	1 1/2	=	=	s.f.
	14	x	15 1/3	x	1 5/12	=		
	14	x	8	x	2 1/4	=		

The first number written out is 22 and represents the number of footings being formed. The second dimension is 19⅓ and represents the perimeter of the lower block. The third dimension is 1⅙ and represents the height in feet of the lower block. On the next line below occur the dimensions of the formed surfaces of the upper block of the exterior footings treated in the same manner. The interior footings are treated in the same way. The product of these figures as shown will give the surfaces of concrete in the footings which must be provided with forms, and is to be priced out in the estimate as "surface measurement."

Forms for Foundation Walls.—In scaling the forms for foundation walls it must be remembered that both sides of the wall are to be formed, hence the first figure written down must be the figure 2. The figures shown below represent the correct tabulation of the form dimensions for the concrete foundation wall as scaled from Fig. 3.

Forms-Foundation walls.								
South-	2	x	160	x	3 1/12	=		
pilasters (sides)	(2x7)	x	9/12	x	3 1/12	=		
East-	2	x	(60-1 1/3)	x	3 1/12	=		
pilasters	(2x2)	x	9/12	x	3 1/12	=		
North-	2	x	160	x	3 1/12	=	=	s.f.
pilasters	(2x7)	x	9/12	x	3 1/12	=		
West-	2	x	(60-1 1/3)	x	3 1/12	=		
pilasters	(2x2)	x	9/12	x	3 1/12	=		
edge of paving	[(2x160)+(2x60)]	x			9/12	=		

First the figure 2 denotes that two sides are formed. Next in order is found the length of the wall to be formed, and last the height of the formwork. Both the length and height dimensions of the wall are taken directly from the concrete scaling. The piers are projections on the face of the wall and, as the face of the pier is already measured when the face of the wall is taken, it is necessary to add only the surfaces of the edges of the piers to complete the foundation wall forms. The corner piers do not increase the amount of formed surface and may be neglected in writing out the form dimensions. Forms must be provided for the edge of the paving concrete and this is usually added to the foundation wall forms.

Forms for Exterior and Interior Columns.—In writing out the form dimensions for exterior columns and other rectangular or notched columns, the same rules are followed as have been laid

down for footing forms. There are but three dimensions or numbers to write down on the estimate sheet, viz., number of columns, perimeter of column, and height of the surface formed. These dimensions may be taken directly from the concrete scaling.

The forms for round columns and column heads are usually made of sheet steel or iron and instead of determining the square feet of formed surface it is necessary only to list the number of columns formed, the diameter and the height of the columns. The forms for the brackets are determined by simply listing the number of brackets and determining the approximate number of square feet in one bracket. The formed surface of the bracket should be kept separate from the main column forms as the unit price of labor is at least double for this work. Below will be found the form dimensions for the exterior and interior columns as taken from the concrete scaled or from Figs. 4 and 5.

Forms-Exterior columns								
1st story	18	x	7 5/8	x	11	=	} =	s.f.
corner cols.	4	x	10 2/3	x	11	=		
mullion			4 2/3	x	11	=		
brackets	18	x	9 sq. ft.			=		
2nd story	18	x	7 7/8	x	11 1/2	=		
corner cols.	4	x	10 2/3	x	11 1/2	=		
mullion			4 2/3	x	10	=		
brackets	18	x	9 sq. ft.			=		
Forms-Interior columns and heads								
steel forms	20" dia. - 10'-8" long							#14
	14" dia. - 11'-2" "							#14

Forms for Floor Slabs and Roof Slab.—In writing out the forms for flat slabs it is only necessary to determine the area of the slab. The length and width dimensions of the slab are taken directly from the scaled dimensions of the concrete without reference to the plans. The areas of the bottoms of the drop panels should be deducted by referring to the scaling of the concrete in the drop panels. If the slab forms are for the beam and girder type of floor, the area of the slab is determined as above and then the beam bottoms are deducted from the slab areas. To deduct the beam bottoms it is necessary to refer to the scaled dimensions of the floor beams and girders and select the dimensions which represent the bottom surfaces of all beams occurring in the floors. Deductions for openings are made from form quantities only when the area equals or exceeds 25 sq. ft., and then the full opening should not be deducted as an allowance must be made for the formwork required to form the concrete at the edge of the opening. The forms for the concrete floor and roof slab scaled on p. 1101 have been properly written out below and comparisons should be made with the concrete scaling in order to fully understand the method.

Forms Floor slabs and roof slab									
2nd floor			159 2/3	x	59 2/3		=	} =	s.f.
deduct stair opg.			17	x	8 3/4	Ddt	=		
deduct drop panels	14	x	7 1/2	x	7 1/2	Ddt	=		
roof			160	x	60		=		
deduct drop panels	14	x	7 1/2	x	7 1/2	Ddt	=		

Forms For Drop Panels.—Drop panels are part of the floor slab concrete and as the areas of the bottoms of the drop panels have been deducted from the floor slab it is necessary to add this area back again under this heading. The formed areas of the edges should also be added to the area of the bottoms. No deduction is made for the opening in the bottom of the drop panel form where the column head joins the drop panel. The dimensions written out below represent the formed areas of the concrete in the drop panels as scaled from Fig. 5.

Forms-Drop panels								
2nd floor	14	x	7 1/2	x	7 1/2	=	} =	s.f.
edge	14	x	30	x	1/3	=		
roof	14	x	7 1/2	x	7 1/2	=		
edge	14	x	30	x	5/12	=		

Forms For Wall Beams.—To properly write out the forms for wall beams, curtain walls, parapet beams, etc., it is necessary to observe the rules laid down for foundation walls. Both sides are formed, hence the necessity of the figure 2 appearing before the dimension representing the linear feet of wall beam. The height of a wall beam is figured from the inside vertical height. As this leaves the outside edge of the floor slab without forms, it is necessary to add an area of formed surface equal to the perimeter of the building multiplied by the thickness of the floor slab. This takes account of all exposed surfaces to be formed except the projecting sides of the concrete in the columns at the floor level for a height equal to the thickness of the floor slab only. This is so small that it may be neglected. The forms for the parapet are written out following the same principles as outlined for wall beams. The forms for the wall beams and parapet in Fig. 4 have been properly shown below and comparisons with the corresponding concrete scaled from Fig. 4 should be made.

Forms—Wall beams									
2nd floor	2	x	{370 2/3}	x	1 1/2	=	}	=	s.f.
edge of slab	[(2x160)+(2x60)]			x	2/3	=			
roof parapet	2	x	43 1/3	x	2 5/6	=			
projections			440	x	1/4	=			
edge of slab	[(2x160)+(2x60)]			x	1/2	=			

Forms For Interior Floor Beams.—If no sketches appear in the "description" column of the scaling of the concrete in the floor beams, it is assumed that a slab of uniform thickness rests upon the beams. The number of beams and length of the beams are first written down as for other concrete members of similar structure. As the scaled dimension of the beam height is taken to the bottom of the slab only, it is quite simple to compute mentally the sum of the two side dimensions plus the bottom dimension. This represents the formed area of one linear foot of beam and should be written down in the fourth or "width" column of the estimate sheet. The product of these dimensions will give the area of the formed surfaces of the interior floor beams. If accompanying sketches show that other formwork is necessary to completely form the beam, proper additions should be made to take care of this work. The formed surfaces of the concrete as scaled in the floor beams shown in Fig. 6 are somewhat irregular as they occur at stair openings. The quantities of this formwork appear below.

Forms—Interior floor beams							
2nd fl. Bm. #1	18 1/4	x	4 2/3	=	}	=	s.f.
" #2	10	x	5	=			
" #2	7 1/2	x	4 1/4	=			

Forms For Partitions.—In writing out the formed areas of concrete partitions, the same rules are observed as for other wall forms. Openings are not deducted unless the area of the opening equals or exceeds 25 sq. ft. The formed areas for the concrete partitions shown in Fig. 6 are given below.

Forms—Partitions									
1st story	2	x	(28 3/4)	x	11	=	}	=	s.f.
2nd story	2	x	(28 3/4)	x	11 1/6	=			

Forms For Window Sills, Copings, Stairs and Landings.—No formed areas are computed for window sills, copings, stairs and landings as the unit price appearing opposite the summarized quantity of concrete is made up to include the cost of formwork and reinforcement as well as concrete, hence the forms are not written out.

Formed Surfaces—Carborundum Rubbed.—Referring back to the subject of carborundum rubbing, since the form dimensions are written out, it is very simple to determine the square feet of surface to be rubbed. This may be done very quickly by picking out from the formed

areas the surfaces which, according to specification, must be treated in this manner. It will be found most convenient to leave the work of determining the area of concrete surfaces to be rubbed until after the extension of the form dimensions has been completed. The surface measurements of all formed surfaces will then be found in the "quantity" column reduced to square feet, and the total area of the rubbed surfaces may be quickly determined.

2d. Reinforcement.—Scaling the quantity of reinforcement in a concrete building is a process by which the tonnage of steel bars is obtained. It is not necessary to make a schedule of the bars in the entire building, as it means a large amount of tedious work and in the end the same result is obtained. Footing reinforcement is usually scaled by listing the size of the bars first, then the number of bars needed, and finally the length of the bar itself. Oftentimes it will be found convenient to compute the number of pounds of reinforcement in a footing and then multiply by the number of footings. Reinforcement in foundation walls may be figured at the number of pounds per square foot of wall. Column reinforcement is usually taken off the plans in detail, listing the size, number of bars, and the length of the bars in the regular order. Slab reinforcement is almost always computed on the square foot basis and all beam reinforcement by the number of pounds per lineal foot of beam. Curtain wall and partition reinforcement is computed by the number of pounds to a square foot of reinforced surface. In computing reinforcement on the square foot and lineal foot basis, care must be taken to allow for all secondary steel, laps for bond, stirrups, construction bars, waste, etc. It will require careful practice in order to scale reinforcement accurately by this method, but once thoroughly understood, it will be found a very reliable and rapid method. The reinforcement is listed in the same order as the forms and the different types may be easily grouped for pricing.

2e. Excavation—*General or Steam Shovel Excavation.*—General excavation is the term applied to the process of removing the earth for basements, or cutting down the grade to the paving level. General excavation does not include the excavation for the footing holes below the paving level or other small excavated areas where hand work entirely must be used. Steam shovels, scraper diggers, or hand work may be used in general excavation and when the quantity is scaled for estimating purposes, notation should be made of the probable method to be employed in doing the work. In scaling the dimensions for general excavation the order should be the same as for scaling concrete work, viz., length, width, and height, and should be written down in the proper columns of the estimate sheet. Proper allowance should be made for slope of the earth work outside of the exterior footings when the length and width dimensions are scaled. If the general excavation is done by hand, vertical sheeting may be used instead of excavating to a slope. All these conditions should be noted in the "description" column when the scaling is done.

Footing Excavation.—The labor of removing earth for footing holes, pits, trenches, etc., is nearly always done by hand and should be described on the estimate sheet as "Footing Excavation." In scaling the quantities for footing excavation the nature of the soil to be removed should be noted as well as the location of the footing hole in respect to the plans. Footing holes excavated to a depth exceeding 4 ft. should be scaled net, that is, add but 6 in. to the length and width dimensions of the footing for the size of the excavated hole. This allows for the thickness of the sheeting lumber generally used in connection with footing excavation exceeding 4 ft. but not exceeding 10 ft. in depth. In scaling footing excavation when the depth is less than 4 ft., no sheeting is used but proper allowance is made in scaling dimensions to allow for the slope of the earth work. When sheeting is used for footing excavation the sheeting usually serves as formwork for the lower block of concrete in the footing.

Backfill.—Backfill is a term applied to the labor of rehandling excavated material after the footings have been placed and it becomes necessary to fill in around the footing, wall, or other foundation work. This quantity usually equals the amount of earth removed in excavating for the footing, as the amount of earth which is left after the footing hole is properly backfilled must be rehandled and disposed of in some other way. Where the earth work is a large part of the job operations, the backfill and general disposition of excavated material should be carefully considered.

Sheeting.—As the form dimensions are written out from the scaled dimensions of the concrete work, so are the sheeting dimensions written out from the scaled dimensions of the excavation. Sheeting is estimated by the square feet of surface measurement of earth retained. No allowance is made for the distance the sheeting penetrates the ground below the bottom of the excavated hole or for the distance above the top of the earth work retained.

2f. Masonry—*Brick Work.*—Brick work, where more than 4 in. thick, is estimated by the cubic foot. In order to determine the cubic feet of brick work in a wall, the dimensions are scaled in the same manner as outlined for "Concrete Partitions." In scaling the brick work in the exterior walls of a building, the work should be done by elevations and adequate description given to make it easy to check over the work to see if any part has been omitted. The quantities should contain the actual number of cubic feet of brick work to be built and no more. All openings should be deducted exactly as they are shown and no allowances made in the quantity to take care of work which may be more or less expensive to construct than the average unit price will pay for. After the actual cubic feet of brick work in a building is determined, the unit price should then be made up to correspond with the class of work to be built.

Brick Veneer.—Brick veneer is usually laid up 4 in. thick and is so noted in the "description" column together with other notations regarding the character and location of the work. As brick veneer is estimated by the square foot in scaling the quantity, it is necessary to determine the length and height only of the work, using columns No. 4 and No. 5 in which to write down these dimensions. The work should proceed by elevations as in the case of scaling other classes of brick work.

Terra Cotta Partitions.—Partitions built from hollow terra cotta blocks are estimated by the number of blocks laid up in a wall. As nearly all hollow terra cotta blocks have a face measurement of one square foot each, the number of blocks in the terra cotta wall corresponds to the number of square feet in the face of the partition. In scaling the square feet of terra cotta partition, it is necessary to observe the same methods as were laid down for scaling "Concrete Partitions." Notation should always be made in the "description" column regarding the type of block specified and the thickness of the partition. All deductions should be accurately made. It may be stated here that the mortar joints in the work offset the usual breakage of the blocks in transit and no allowance therefore need be made for either mortar joints or breakage.

2g. Plastering.—Plastering is measured by the square yard of surface measure and the dimensions making up the quantity are usually taken directly from the scaled dimensions of the terra cotta partitions, ceilings, walls, or other surfaces in a manner similar to the way in which carborundum rubbed surfaces are determined. In the "description" column should be noted the number of coats called for, kind of cement specified, and other notations helpful in deciding upon proper unit prices.

2h. Steel Sash.—In estimating steel sash, the important points to consider are size of opening, uniformity of size and type, percentage of ventilation, and operation. The "description" column should contain information relative to all these points. In scaling the size of the opening the number of identical sash should first be listed in the second column of the estimate sheet. The length and height of the openings should follow in the third and fourth columns respectively. The sash openings should be scaled by elevations as by this method omissions of a large character would be quickly noted when the dimensions were extended.

2i. Glass and Glazing.—After noting in the "description" column the kind and size of glass specified, it is a simple matter to determine the number of square feet of glass required to glaze the sash. For estimating purposes it is sufficiently close if we assume that 90% of the sash area is made up of glass. Therefore, the glass required is usually carried out on the estimate sheet as 90% of sash area.

2j. Doors, Frames, and Hardware.—In listing the doors, frames, and hardware in a building, the doors should be considered individually or by types. The location and character of the door should be noted in the "description" column together with notations as to frame and hardware. In writing down the size of the door, the width should be first con-

sidered and the height last. For instance, a door 2 ft. 8 in. wide by 6 ft. 8 in. high should appear on the estimate sheet as $\frac{2}{8} \times \frac{6}{8}$. The number of doors of a kind is written down in the "summary" column as the scaling is done.

2k. Light Iron Work and Miscellaneous Iron.—No special ruling can be set down as governing the scaling of light iron work for general estimating purposes. The estimator should list intelligently all such material and at the same time endeavor to scale the dimensions in a manner which will result in the quantity being reduced to the proper basis for pricing out. Pipe hand rails should be in lineal feet, safety stair treads in lineal feet, steel inserts by the piece, cast-iron scuppers by the piece, and curb angle guards by the lineal feet at so many pounds per foot, etc., etc. It is also customary to carry out in the "total" column a certain sum of money decided upon in the judgment of the estimator as adequate to cover miscellaneous iron work not shown or called for on plans or in specifications, but which invariably must be supplied by the builder.

2l. Roofing and Flashing.—The roofing dimensions are usually taken directly from the scaling of the concrete for the roof slab. This is generally full measure as the parapet beams reduce the roofing area slightly below the slab area but as roofing is measured in units of squares (100 sq. ft.) the result is quite correct. In scaling the roofing area, it is first necessary to note in the "description" column the kind of roofing required and the guarantee. Flashings are a part of the roofing contract and should be sealed immediately following the roofing. Base and cap flashings are estimated by the lineal foot and notation should be made of the kind of metal specified together with the number of inches in width required to flash one lineal foot. Metal *gravel* strip should be scaled in the same manner. Conductor boxes are estimated by the piece and should be listed in the "summary" column accompanied by proper description.

2m. Painting.—Painting of walls and ceilings is measured by the square yard and as in estimating the amount of carborundum rubbing, the painted surfaces may be determined by referring to the extended dimensions of the form areas of the concrete work. Other painted work, such as brick walls, terra cotta walls, etc., may be determined readily by referring to the quantities already scaled for this work and the total painted areas then reduced to square yards and written down in the "summary" column.

Painting steel sash and doors is also measured by the square yard. To determine the amount of painting on the steel sash and doors of a building, refer to the scalings for the sash and doors adding together the flat areas just as though the entire areas were to be painted like a door. Double this area as doors and sash are painted two sides. Then divide this amount by 9 and the result is the square yards of painting to be estimated, and should appear in the "summary" column of the estimate sheet.

Painting light iron, miscellaneous iron, etc., is usually a small item and is not figured on a square yard basis, but rather by the judgment of the estimator. The amount of money allowed for this depends entirely upon the miscellaneous iron to be painted and each job is considered individually.

2n. Engineering, Plans, Etc.—Sometimes the builder is called upon to include in his estimate the cost of preparing designs and plans for the work to be estimated. The percentage of cost varies with the type of building and the skill of the engineers doing the work. Ordinarily the plans of a regular reinforced concrete factory can be prepared, from the surveys to the finished drawings and details, for 3% of the net cost of the completed structure.

2o. Clean Up The Job At Completion.—The estimator must allow a sum of money sufficient to cover the cost of cleaning up the job at completion, removing debris from the site, washing windows, and leaving job broom clean.

2p. Liability Insurance.—An item must be included in the estimate which will cover the cost of carrying liability insurance for the period of the job. The rate varies in different localities and with different contractors. The percentages may run as low as 3% of the amount expended for labor costs. As the labor expense involved in constructing a regular reinforced concrete building amounts to about one-third of the total cost of the building, the amount of money to be allowed for liability insurance premiums is easily determined when the rate is known. For instance, suppose the rate is 6% of the labor and the total estimate amounts to $62,000 without profit. If this building is a regular reinforced concrete factory, the labor involved would be about one-third of $62,000 or approximately $21,000. Com-

puting 6% of $21,000 we have $1260. The amount of money carried in the estimate for liability insurance premiums could well be taken at $1250.

2q. Watchman.—In order to estimate the cost of employing a watchman while a building operation is going on, it is first necessary to determine approximately the number of weeks required to construct the building. This decided upon, it is a matter of computing the expense of employing a watchman for this length of time at a proper weekly wage.

2r. Superintendence, Job Overhead, Office Expenses, Etc.—Under this head must be included all the expense attached to maintaining a job office, including the job superintendent. It is the usual custom to determine the amount of this expense for one week and multiply this amount by the number of weeks this office must be maintained. Under the head of "Superintendence, Office, Etc.," must be figured the wages of the following men: job superintendent, time keeper, chief office clerk, and tool boy. On specially large jobs the office force will consist of more men than above listed, while on a very small job the personnel may be cut down by arranging to have the chief clerk act as timekeeper in connection with his other duties. The cost of telephones, stationery, railroad fares, freight on supplies, building and dismantling office, etc., must be considered. These are items which may be easily estimated at too low a figure. Proper consideration should be given to every expense entering into this item if the estimate is to be an accurate one in which allowance has been made for proper and competent job management.

2s. Sundries.—It often occurs that estimates are made from plans not completely finished or from poorly prepared drawings. The uncertainty attached to making estimates from such plans makes it advisable to conclude the estimate with an item for sundries, the amount of which should be determined in the estimator's judgment as being adequate to protect his estimate against over-runs due to his having omitted some work implied but not shown or called for. The amount of this item should be based on a percentage of the total estimated cost not including profit and usually runs from 2 to 5% according to the condition of the plans. It is very seldom an estimate should be prepared without any allowance for over-runs due to unforeseen conditions.

2t. Profit.—The percentage of profit is figured on the total cost of the work including labor and material, etc. It may be a very low percentage or may be very high, depending entirely on the basis the contractor is operating his business. Eight per cent is considered a very low profit and the contractor must do a large volume of business and keep his job organization well employed in order to be successful at this rate. Percentages of profit will run from 8 to 15% and sometimes higher. For ordinary estimating purposes, 10% may be assumed as a fair profit for the builder of reinforced concrete buildings, unless the job costs will run under $50,000 total cost, in which case 12% profit should be added to the estimate.

3. Estimating Unit Prices.—The two principal elements which constitute unit prices in general are labor and material. In order to arrive at a correct unit price for a certain building operation it is necessary to know very closely how much labor is involved to perform a unit of this work and also how much material will be required. The items of labor and material must be estimated separately and then combined, comprising as a whole, the unit price to be used in the estimate. Every step involved should be carefully analyzed and correct values calculated for the labor and material in each step. Unit prices which have been intelligently prepared in this manner will usually represent to a close degree the cost of the finished work.

The unit prices given in this chapter are based on the labor rates and material costs prevailing in New England at the time this paper was prepared. As unit costs vary greatly in different localities and with the changing markets of labor and material, the unit prices shown here should be viewed with caution for estimating purposes. The volume of material and labor being priced has an important bearing on the unit price, and it should be borne in mind that a correct unit price for estimating purposes should be built up from the circumstances and conditions peculiar to the job being estimated and it cannot be obtained in any other manner.

For this estimate, it is assumed that common laborers receive an average wage of 50 cts. per hr. Carpenters, masons, and other skilled building labor receive 90 cts. per hr.

3a. Concrete.—The unit prices for the concrete in the foundations is made up by first ascertaining the amount of material and labor necessary to make one cubic yard of con-

crete mixed in the proportion of 1–3–6. Experience has shown that to estimate the quantity of cement, sand, and crushed stone from tables set forth in text books would result in a shortage of materials, as allowance for a certain amount of waste must be made. It will be noted that in working out the amounts of material in the following calculation, proper allowance has been made for this waste.

Concrete—per cubic yard (1–3–6 mix)	
Cement $1\frac{1}{10}$ bbl. at 2.77	$3 05
Sand $\frac{1}{2}$ cu. yd. at 1.95	0 98
Cr. stone $1\frac{3}{10}$ tons at 2.75	3 58
Plant	2 10
Labor, mixing, and placing	1 75
Total cost per cu. yd	$11 46
	(Use $11.50 for unit price.)

The price of cement is obtained from the cement dealers ($2.84 per bbl. f. o. b. cars job). In this price is an allowance for 4 cement bags which if returned to the dealer in good condition would be credited at 10c. each or 40c. per bbl. A cash discount of 5c. per bbl. is also allowed if payments are promptly made. Taking advantage of both these credits (45c.) the net cost of the cement becomes $2.39 per bbl. Unloading and storing the cement in a cement shed costs usually 25c. per bbl. Tests must be made by a Cement Testing Bureau to ascertain the quality of the cement, for which an average charge of 3c. per bbl. is made. The loss of credits due to injury to bags in transit, and to the cost of freight on returned bags amounts to about 10c. per bbl. of cement purchased. Allowance being made for the above charges, the price of cement becomes $2.77 per bbl. and it is this figure which is used in working out the cost of concrete. The following calculation shows how this price is determined.

Cement—Dealer' quotation, f.o.b. cars job		$2.84
Credit for bags	0 40	
Cash discount	0 05	
		$2 39
Unloading and storing cem		0 25
Testing cement		0 03
Loss and freight on empty bags		0 10
Total cost per bbl		$2 77
Sand—Dealer's quotation, f.o.b. cars job		$1 75
Unload and handle into bins		0 20
Total cost per cu. yd		$1 95
Crushed stone, f.o.b. cars job		$2 50
Unload and handle into bins		0 25
Total cost per ton		$2 75

As a certain amount of machinery, chutes, runways, towers, etc., are required in the process of placing concrete, an allowance must be made in the unit price for the labor of erecting and dismantling this "plant work" as it is commonly called, and also allowance must be made for plant material purchased or rented for the duration of the job. This item varies with the size and type of the job and it may run as low as $1 per cu. yd. and in especially difficult jobs would cost $3 or more per cu. yd. of concrete placed. A plant cost of $2.10 per cu. yd. has been included in the unit price of the concrete estimated herein, and the subdivisions of this cost are listed on. p. 1112:

The average labor cost of mixing and placing concrete in a reinforced concrete building with common labor at 50c. per hr. is about $1.75 per cu. yd. when modern plant equipment is used on the job. A saving of 25c. on the labor cost and 25c. on the plant cost per cu. yd. is usually made in placing paving concrete, making the unit for this class of work, 50c. less than for other concrete work of a similar mix.

Plant cost per cubic yard of concrete:

	Labor	Material or rental charge
Towers	0 20	0 20
Temporary bldgs.	0 12	0 15
Bins for aggregate	0 10	0 20
Mixer and motor	0.06	0.14
Canvas and chutes	0 05	0 35
Runways, staging and small tools	0 14	0.24
Fuel, power and water		0.15
Labor	0 67	Material and rentals 1 43
Total per c yd.		$2.10.

The unit price of concrete mixed in the proportions of 1-2-4 and 1-1½-3 is made up in a similar way. No change is made in the quantity of sand, crushed stone, labor, and plant. The cement quantity alone is changed. The computation for 1-2-4 and 1-1½-3 concrete follows:

Concrete—per cubic yard (1 2-4 mix)	
Cement 1⅝ bbl. at 2.77	$ 4 62
Sand, ½ cu. yd. at 1.95	0 98
1³⁄₁₀ tons of crushed stone at 2.75	3 58
Plant	2 10
Labor, mixing, and placing	1 75
Total cost per cu. yd.	$13 03
	(Use $13 for the unit price.)
Concrete—per cubic yard (1-1½-3 mix).	
Cement, 2 bbl. at 2.77	$ 5 51
Sand ½ cy. at 1.95.	0 98
Cr. stone 1³⁄₁₀ tons at 2.75	3 58
Plant	2 10
Labor, mixing, and placing	1 75
Total cost per cu. yd	$13 95
	(Use $14 for unit price.)

The unit price of concrete window sills of about standard size usually runs around 72c. per lineal foot including concrete, forms, reinforcement, and finish. The price of 72c. per lin. ft. is made up as follows:

Concrete at 50c. per cu. ft.	$0 27½
Formwork at 25c. per sq. ft.	0 25
Reinforcement at 0.05c. per lb.	0 07½
Carborundum rubbing (outside)	0 12
Total cost per lin. ft.	$0 72

The cost of constructing reinforced concrete stairs using rates of labor and materials as previously noted, is about $1.50 per lin. ft. of nosing. Landings will cost about 75c. per sq. ft. These unit prices include all concrete, forms, reinforcement and cement finish necessary to complete the stairway. No safety treads or hand rails are included.

Granolithic finish 1 in. thick laid after the slab concrete has set will cost about 11c. per sq. ft. for material and labor. The unit price is made up as follows:

1-in. granolithic finish laid after—per 1000 sq. ft.	
Cement, 12½ bbl. at 2.77	$ 34 63
Pea stone, 4 tons at 3.00.	$ 12.00
Labor to pick and clean floor preparatory to laying finish, mix and lay grano. finish including plant costs and protect while drying	65 00
Total cost per 1000 sq. ft.	$111.63
	(Use 11c. per sq. ft. for unit price.)

Note: No sand required in granolithic finish.

If the granolithic finish is laid before the concrete in the slab has become thoroughly dried-out, the finish is called an integral finish. In estimating a finish of this kind, since the thick

ness of the granolithic finish is included in the slab concrete quantities, the unit price should contain only the labor cost of the cement finishers' time and the cost of the extra cement used in the top part of the slab which forms the finish, and the increased cost of using pea stone instead of ordinary crushed stone. The unit price for integral granolithic finish is made up as follows:

1-in. granolithic finish—laid integral per 1000 sq. ft.	
Extra cement, 10 bbl. at 2.77	$27 70
Labor, finisher's time	30 00
Extra cost of pea stone, 4 tons at $3.00	12.00
Total cost per 1000 sq. ft.	$69.70
	(Use 7 cts. per sq. ft. for unit price.)

The unit of cinder concrete crickets placed on the roof to form proper slope to downspouts has been worked out in detail as follows:

Cinder concrete—per cubic yard.	
Cement, 1 bbl. at 2.77	$2 77
Cinders, 1 cu. yd.	1 50
Plant costs...	2 50
Labor—mix and place to slope	2 25
Total cost per cu. yd....	$9 02
	(Use $9 for unit price.)

The cost of finishing concrete surfaces with carborundum stone and cement varies greatly with different contractors. A good finish may be obtained by going over the surface of the concrete twice at a total cost of about 7½c. per sq. ft. of surface treated. The unit price is made up as follows:

Carborundum rubbing—2 coats—per 1000 sq. ft.	
Labor, 1st rub.	40 00
Labor, 2d rub.	30 00
Cement used ½ bbl. at 2 77	1 38
Total cost per 1000 sq. ft.	71 38
	(Use 7½c. per sq. ft. for unit price.)

3b. Forms. In working out a unit price for formwork it is very important to know how many times the forms can be used without remaking. If it is possible to use the forms twice, one-half the cost of the lumber should be charged against the unit for each use. If the forms are used three times a lumber charge of one-third the cost of the lumber is included in the unit price and so on. The cost of erection and stripping the formwork remains uniform for each use but some saving is made on making when the forms are used more than once. In forming one square foot of concrete surface, about 3 board feet of lumber are used in building the formwork. Hence, if the forms are used but once the material charge in the unit price will be the cost of 3 board feet of lumber. If the formwork is used twice it will be necessary to make a material charge of only 1½ board feet of lumber and so on. Some salvage of the lumber is usually made at the completion of the job; however, where the formwork is very complicated, the lumber is practically ruined and no salvage is realized. Ordinarily a saving of about 15 % of the cost of the lumber is realized at the close of the job. A certain amount of machinery is required with which the formwork is constructed on the job, consisting principally of a saw mill and motor, small tools, nails, etc. This is the "plant cost" and seldom amounts to more than 1c. per sq. ft. of concrete surface formed. The labor involved in making, erecting, and stripping the formwork varies with the complexity of the work but seldom costs less than 7c. or more than 15c. per sq. ft. of concrete surface formed. The cost of the labor of forming a concrete cornice or other similar work will cost much more than this maximum.

The unit costs for formwork given below have been worked out with lumber at $60 per M, f.o.b. cars at the job. Adding to this $2.50 per M to cover the cost of unloading and handl-

ing the lumber at the job, the price becomes $62.50 per M. The building will probably require a set of forms for one complete story, and with a small amount of remaking these forms may be used for forming the second or top story. This having been decided upon, it follows that the unit price should contain a material charge equal to the cost of 1½ board feet of lumber. This material charge is maintained throughout the unit prices for formwork so long as two uses are reckoned on.

The common labor is figured at 50c. and carpenters' work at 90c. per hr.

Footing Forms:

Lumber 1½ board feet at $62.50 per M	$0.0938	
Deduct salvage	0.0150	0.0788
Plant cost		0.0100
Labor, make, erect, and strip		0.0800
Total cost per sq. ft.		$0.1688
		(Use 17c. for unit price)

Foundation Wall Forms:

The unit price for foundation wall forms may be figured similar to footing forms with the exception that the labor will cost about 9c. instead of 8c. per sq. ft. This change adds 1c. per sq. ft. to the unit price, making the unit price for foundation wall forms 18c. per sq. ft.

Exterior Column Forms:

Lumber 1½ board feet at $62.50 per M	$0.0938	
Deduct salvage	0.0150	0.0788
Plant costs		0.0100
Labor, make, erect, and strip		0.1175
Total cost per sq. ft.		$0.2063
		(Use 20½c. for unit price.)

Bracket Forms:

Lumber, 1½ board feet at $62.50 per M (no salvage allowed)	$0.0938
Plant	0.0100
Labor, make, erect, and strip	0.2350
Total cost per sq. ft.	$0.3388
	(Use 33½c for unit price.)

Interior Column Forms—(round steel):

Rental of steel column forms each	$15.00
Labor, erect, strip, and handle	5.00
Total unit cost each	$20.00

Flat Slab Floor and Roof Forms:

Lumber, 1½ board feet at $62.50 per M	$0.0938	
Deduct salvage	0.0150	0.0788
Plant		0.0100
Labor, make, erect, and strip		0.0775
Total cost per sq. ft.		$0.1663
		(Use 16½c. for unit price.)

Drop Panel Forms:

Lumber, 1½ board feet at $62.50 per M (no salvage allowed)	$0.0938
Plant	0.0100
Labor, make, erect, and strip	0.1075
Total cost per sq. ft.	$0.2113
	(Use 21c for unit price.)

Wall Beam Forms:

Lumber, 1½ board feet at $62.50 per M	$0.0938	
Deduct salvage	0.0150	0.0788
Plant		0.0100
Labor, make, erect, and strip		0.0975
Total cost per sq. ft.		$0.1863
		(Use 18½c. for unit price.)

Floor Beam Forms:

The unit cost of floor beam forms works out quite closely to the cost of the wall beam forms, the only difference being an increase of about ½c. per sq. ft. in the labor charge. This increase makes it necessary to use 19c. as a unit price for floor beam forms. Should the floor be what is known as a beam and slab type of floor, the average labor cost of making, erecting, and stripping the forms, measuring beams and slab together will be about 8½c. per sq. ft. This would make the cost of beam and slab floor forms about 17½c. per sq. ft. if the forms are used twice.

Partition Forms:

Lumber, 1½ board feet at $62.50 per M	$0 0938	
Deduct salvage	0 0150	0 0788
Plant		0 0100
Labor, make, erect, and strip		0 1375
Total cost per sq. ft.		$0 2263
		(Use 22½c. for unit price.)

3c. Reinforcement.—The labor of cutting, bending, and placing reinforcement will cost from $8 to $20 per ton depending upon the size of the bar, the amount of bending required, and the position in which the bars must be finally placed. In the average concrete building, it is safe to assume that a flat rate of $14 per ton will cut, bend, and place the reinforcement in the building. The unit price of 4¼c. per lb. is made up as follows:

Reinforcement f.o.b. cars job, per ton	$68 00
Unload and pile on job	3 00
Cut, bend, and place including wire, etc.	14 00
Total cost per ton	$85 00
	(Use 4¼c per lb. for unit price.)

3d. Conclusion.—The method of arriving at the unit costs of the principal parts of a reinforced concrete building have been briefly outlined in the previous paragraphs. With the aid of this information and by ascertaining the costs of material used in concrete construction, it is possible to make estimates of reinforced concrete buildings which should represent quite closely the final cost if the work is expeditiously performed. Space does not permit the compilation of the vast volume of matter necessary to cover the subject of unit prices thoroughly. Enough information has been given, however, to enable the structural engineer to estimate for himself the probable cost of the structure he has designed and the builder not familar with reinforced concrete construction may be able to make some use of the subject matter on these pages.

SECTION 3

ARCHITECTURAL PRACTICE

By Arthur Peabody

1. Architects' Rates for Service.—The architects' commissions will be computed on the percentages recommended by the American Institute of Architects. These will vary with the nature of the work, whether large or small, and whether the amount of service is to be partial or complete. Rates for remodelling and for monumental or decorative work will be different from the regular rate. The recommended rates for ordinary examples of the above are here given. ("Reprinted from the Standard Documents by permission of the American Institute of Architects.")

1. The Architect's professional services consist of the necessary conferences, the preparation of preliminary studies, working drawings, specifications, large scale and full size detail drawings; the drafting of forms of proposals and contracts; the issuance of certificates of payment; the keeping of accounts, the general administration of the business and supervision of the work, for which, except as hereinafter mentioned, the minimum charge, based upon the total cost of the work complete, is 6%.

2. On residential work, alterations to existing buildings, monuments, furniture, decorative and cabinet work and landscape architecture, it is proper to make a higher charge than above indicated.

3. The Architect is entitled to compensation for articles purchased under his direction, even though not designed by him.

4. Where the Architect is not otherwise retained, consultation fees for professional advice are to be paid in proportion to the importance of the question involved and services rendered.

5. The Architect is to be reimbursed the costs of transportation and living incurred by him and his assistants while traveling in discharge of duties connected with the work, and the costs of the services of heating, ventilating, mechanical, and electrical engineers.

6. The rate of percentage arising from Art. 1 and 2 hereof, *i.e.*, the basic rate, applies when all of the work is let under one contract. Should the Owner determine to have certain portions of the work executed under separate contracts, as the Architect's burden of service, expense and responsibility is thereby increased, the rate in connection with such portions of the work is greater (usually by 4%) than the basic rate. Should the owner determine to have substantially the entire work executed under separate contracts, then such higher rate applies to the entire work. In any event, however, the basic rate, without increase, applies to contracts for any portions of the work on which the Owner reimburses the engineer's fees to the Architect.

7. If, after a definite scheme has been approved, the Owner makes a decision which, for its proper execution, involves extra services and expense for changes in or additions to the drawings, specifications or other documents; or if a contract be let by cost of labor and materials plus a percentage or fixed sum; or if the Architect be put to labor or expense by delays caused by the Owner or a contractor, or by the delinquency or insolvency of either, or as a result of damage by fire, he is to be equitably paid for such extra service and expense.

8. Should the execution of any work designed or specified by the Architect or any part of such work be abandoned or suspended, the Architect is to be paid in accordance with or in proportion to the terms of Art 9 of this Schedule for the service rendered on account of it, up to the time of such abandonment or suspension.

9. Whether the work be executed or whether its execution be suspended or abandoned in part or whole, payments to the Architect on his fee are subject to the provisions of Art. 7 and 8, made as follows:

Upon completion of the preliminary studies, a sum equal to 20% of the basic rate computed upon a reasonable estimated cost.

Upon completion of specifications and general working drawings (exclusive of details) a sum sufficient to increase payments on the fee to 60% of the rate or rates of commission agreed upon, as influenced by Art. 6, computed upon a reasonable cost estimated on such completed specifications and drawings, or if bids have been received, then computed upon the lowest bona fide bid or bids.

From time to time during the execution of work and in proportion to the amount of service rendered by the Architect, payments are made until the aggregate of all payments made on account of the fee under this Article reaches a sum equal to the rate or rates of commission agreed upon as influenced by Art. 6, computed upon the final cost of the work.

Payments to the Architect, other than those on his fee, fall due from time to time as his work is done or as costs are incurred.

No deduction is made from the Architect's fee on account of penalty, liquidated damages or other sums withheld from payments to contractors.

10. The Owner is to furnish the Architect with a complete and accurate survey of the building site, giving the grades and lines of streets, pavements and adjoining properties; the rights, restrictions, easements, boundaries and contours of the building site, and full information as to sewer, water, gas and electrical service. The Owner is to pay for borings or test pits and for chemical, mechanical or other tests, when required.

11. The Architect endeavors to guard the Owner against defects and deficiencies in the work of contractors, but does not guarantee the performance of their contracts. The supervision of an architect is to be distinguished from the continuous personal superintendence to be obtained by the employment of a clerk of the works.

When authorized by the Owner, a clerk of the works, acceptable to both Owner and Architect, is to be engaged by the Architect at a salary satisfactory to the Owner and paid by the Owner, upon presentation of the Architect's monthly certificates.

12. When requested to do so, the Architect makes or procures preliminary estimates on the cost of the work and he endeavors to keep the actual cost of the work as low as may be consistent with the purpose of the building and with proper workmanship and material, but no such estimate can be regarded as other than an approximation.

13. Drawings and specifications, as instruments of service, are the property of the Architect, whether the work for which they are made be executed or not.

Note.—The words "the cost of the work," as used in Art. 1 and 9 hereof, are ordinarily to be interpreted as meaning the total of the contract sums incurred for the execution of the work, not including Architect's and Engineer's fees or the salary of the clerk of the works, but in certain rare cases, *e. g.*, when labor or material is furnished by the Owner below its market cost or when old materials are re-used, the cost of the work is to be interpreted as the cost of all materials and labor necessary to complete the work, as such cost would have been if all materials had been new and if all labor had been fully paid at market prices current when the work was ordered, plus contractor's profits and expenses.

2. Employment of Architects.—An architect may be employed in various ways, as on a commission basis or on a salary. He may furnish plans and specifications only, or be employed also to superintend the work. In some states the lien law protects the architect; in others it does not. The architect should ascertain exactly what person, corporation, or authority has the power to employ him and, in every case, obtain a written contract for services. The contract should describe accurately what the architect is to do, and what compensation shall be paid. The enumeration of his duties in minute detail will not be necessary but no uncertainty should exist as to the limit of his employment, whether it be for preliminary sketches, for the general design, for working drawings, specifications and details, of for superintendence. Provision should be made for a proper settlement in the case of failure of the enterprise to start, or to proceed to completion, and for his release if necessary before the completion of the work. The terms of payment must be stated. The contract must be such as will stand in law. Verbal contracts unsupported by witnesses are of no force. The following will be sufficient for small work. For important undertakings the Standard Contract of the A. I. A. should be used.

Short Contract for Architectural Service

. . . . 19

(Place and date)

Article I. This contract certifies that . . . ., Architects, hereby agree to furnish the design, working drawings and specifications, and to superintend the construction of . . . . for . . . . . ., owner.

(Insert the Building or Work to be Done)

Article II. . . . . owner, hereby agrees to pay to the architects for the above work a sum of money equal to per cent of the entire cost of the above building or work.

Article III. Payments shall become due to the architect as follows:

Upon completion of the design . . .	20% of the whole.
Upon completion of the working plans and specifications	40% of the whole.
For the entire superintendence	40% of the whole.

Article IV. The original design, and the plans and specifications shall remain in the custody of the architect, but neither he nor the owner shall use them or copies of them except for the construction of this building or work.

Article V. The architect and the owner for themselves, their heirs, successors, executors, administrators and assigns, hereby agree to the covenants herein contained. In witness whereof they have set their hands and seals the day and year first above written.

. . . .
Signature of Architects

. . . .
Signature of Owner

3. Contracts for Building.—For large enterprises, involving employment by public bodies such as a Board of Trustees, or a building commission, the standard documents of the American Institute of Architects are advisable. These documents cover the conduct of competitions, the employment of architects, building contracts and other matters in connection. The Standard Form of Contract for building will require minor modifications for use in public work, to comply with various state laws. The Engineering Department of the State of Wisconsin makes use of a modified form of the standard contract and bond for important work. Some states require a contract and bond for small work as well. A short form of contract and bond has been adopted

in Wisconsin for all contracts for labor and material in sums of $100 or more. The contract and bond occupy one side of a letter sheet.

STATE OF WISCONSIN
SHORT CONTRACT AND BOND

....
(Here insert name of institution)

....
(Date)

Article 1. ....
(Here insert name of contractor)
.... of ....
the first party, hereby agrees to furnish a satisfactory bond and

to....................................

....

....

....

....

The first party hereby agrees to complete the same on or before

....

Article 2. The ....
(Here insert legal title of board)

the second party hereby agrees to pay the first party for the performance of this contract the sum of .... dollars within ....days after the completion of the contract. Partial payments will be made up to 85% of estimated values, previous to such completion.

Article 3. No laborer, workman or mechanic of the contractor, subcontractor, agent or other person shall, in the performance of this contract, work or be permitted or directed to work more than eight hours in any one calendar day, except in cases of extraordinary emergencies, as provided in section 1729*m*, of the statutes.

The first party hereby agrees to maintain liability insurance sufficient to protect the second party and State against all claims for damage or injury to persons employed upon this work and shall save the second party harmless against all claims for royalties on or infringements of patents on materials of appliances used.

The specifications, plans or diagrams furnished herewith shall constitute part of this agreement the same as if hereto attached.

Article 4. The parties for themselves, their heirs, successors, executors, administrators, and assigns, hereby agree to the covenants herein contained. In witness whereof they have set their hands and seals the day and year first above written.

....
(Signature of first party)

....
(Signature of second party)

This form to be used for items coming under Chapter 388, Laws of 1917.

Requisition No. ....

Division ....

Class and Fund ....

BOND

We ....
(Name of first party, principal)
and we, ...
(Name of surety)
are hereby held and firmly bound unto the second party to the accompanying contract in the sum of ....dollars
(Contract amount)
for the payment whereof the first party, principal and the surety bind themselves, their heirs, successors, administrators and assigns jointly and severally by these presents.

The condition of this obligation is that if the first party shall faithfully perform the said contract and satisfy all claims and demands incurred for the same and shall protect the second party and the State of Wisconsin against all liability, injury, or damage caused by the act or omission of the said first party, his agents or employees, then this obligation shall be null and void. Provided that alterations made in the terms of the contract, or any forbearance on the part of the first or second party thereto shall not release the principal or the surety from their liability hereunder, notice to the surety of any such alteration or forbearance being hereby waived.

Signed and sealed this ....day of

....................19..............

....
(Signature of first party, principal)

....
(Signature of surety)

This certifies that I have been duly licensed as agent for the above company in Wisconsin under license No. .... for the year 19 , and appointed as attorney in fact with authority to execute contract bonds with a minimum of $100 and a maximum of $ .... which power of attorney has not been revoked.

....
(Agent)

The foregoing contract and bond to the amount of $....... are hereby *approved*, the same day and year as first above written.

....
(State Chief Engineer)

....
(Governor of Wisconsin)

4. Schedule of Building Costs.—In the usual case, the architect is engaged to design a building to meet a certain expenditure. This amount should be looked upon as the total of funds available. To bring the matter clearly before the owner a schedule of estimated costs is usually made. This will cover

Architect's commission	$———
Expense for travel, etc.	$———
Cost of survey and other engineering work	$———
The principal contract	$———
Subordinate contracts	$———
Estimated amount for extras	$———
Cost of connection to supplies for gas, water, sewer, electric current, heat and power	$———
Costs incidental to construction such as temporary heat, power and light	$———
Fire insurance	$———
Fire protection, safety provisions	$———
Contingent balance	$

By this the architect and owner will be able to know what is meant by the entire cost. Where the funds cannot be exceeded under any circumstances, the schedule is imperative, in order to proceed with safety. In some cases there must be added amounts for land improvement, including clearing, grading, draining, planting, drives, walks and enclosures, together with main sewers and water lines, railway sidings, walls, tunnels, conduits and electric pole lines.

5. Financing of a Building Project.—The extent to which an architect maps out a building project will depend on conditions. The complete program will begin at the conception of the enterprise and end with the occupation or disposal of the completed work. Where the client has no other adviser, the architect may be consulted upon the probability of its financial success, the amount of funds obtainable by first and second mortgages, stock, bonds and other resources.

A loan of about 50 % of the value of the land and completed building may be obtained usually for building purposes. This is secured by the first mortgage. Deferred payments on the land are covered by a second mortgage. The second mortgage will be held by the original owner of the land, and will become due before the first. Real estate companies sometimes accept such for a certain portion of the land value. A more complicated condition is where the second mortgage is used as security for the preferred stock of a project, while the title or ownership is represented by the common stock. Beside this there may be an issue of bonds of one or more kinds.

The burden of financing a project may include cost of promotion, brokerage commissions, discounts on bonds and preferred stock, etc. The following table indicates what might be a fair approximation to the several items, taking the completed work at 100 %. The financial statement will cover

Cost of land, including all charges necessary to securing the title, estimated	25 %
Cost of building including also fees to architects, engineers, permits, etc., and other incidentals, estimated	55 %
Discounts on bonds, estimated	3 %
Discounts on preferred stock, estimated	6 %
Interest on bonds during construction period, estimated	3 %
Dividends on preferred stock during construction period, estimated	3 %
Taxes and insurance during construction period, estimated	½ %
Fees and incidentals, estimated	½ %
Cost of promotion, estimated	4 %
	100 %

The several items would vary somewhat with conditions. A prospective increase in land value may be anticipated, but this would not affect the computation of actual cost. It may have an effect on the per cent. of loan obtainable by the first mortgage, and might make a readier sale of preferred stock which is sometimes hard to place. The common stock is sometimes used as part payment of the architect, contractor and others interested. The control of the business is held by the common stock, which participates also in the earnings from operation or in profits from sale. In some examples the cost of operation will amount to 40 % of the gross income, leaving 60 % to meet fixed charges such as interest, sinking fund, etc., and to be paid on the common stock.

SECTION 4

CONTRACTS

By Daniel J. Hauer

During the past decade the advance in building construction has been both rapid and marked, and the work is becoming decidedly that of specialists, so that those engaged in this class of construction must be trained and educated in many lines of construction. Buildings are not only covering large areas but are also being constructed to great heights, and many smaller structures are being built in such great numbers as to call for expert management and mass production.

Plans and drawings are necessary for such buildings, but they amount to but little in obtaining the desired structure if the proper contract is not made and explanatory and definite specifications are not drawn up to govern the work of construction. The contract is as essential as the money to pay for building, while the specifications are supplemental to the contract and maintain the standard and quality of the construction.

1. Builders.—Most structures are erected under a contract made between the owner and a contractor, who is called the builder. The term contractor is being confined in its use more and more to those carrying on engineering construction, while the term builder is being used for those contracting for architectural construction. Some builders still call themselves "contractor and builder," but this is gradually being confined to those who do both engineering and architectural construction. In many cases, the builder has but little business dealings with the owner, as the architect of the structure acts for the owner, supervising the structure as well as furnishing the plans and specifications and in every way being in full charge of the construction. Some architects employ a superintendent of construction and keep him upon the work to represent them at all times; there may also be inspectors of the architect and the owner. A builder may be an individual, a firm, or a corporation. Corporations doing business in other than their own states must know the laws governing foreign corporations in states they may enter and conform to them; otherwise, heavy fines may be imposed upon them, thus eating up profits that might otherwise accrue.

2. The Owner.—If the owner is a government, then some legally constituted board, commission, or governing body or official makes the contract with the builder. The contract to be legal must be according to the charter of the governing body, as a city or town, and must conform to the statutes and ordinances or acts governing the proposals for contracts and their making. Such a contract made by a builder that does not conform to law is illegal, and he cannot recover for work done, especially if a tax payer brings an action to prevent payments being made. A builder should, therefore, have the advice of a lawyer in making such contracts as well as knowing the *modus operandi* of public contracts.

The actual owner may not be known to the builder, for the former may act through an agent, as a real estate operator, a financial corporation, a land-holding company, an attorney or trustee; or the architect may act as agent. This shows the need of the builder being assured of his money being paid for work done as per the provisions of the contract. He must make the proper investigations himself and through his banks and attorney before he signs the contract and must have assurance that he is to be paid. It is too late to go into such matters after the contract is executed and construction started. Likewise, the owner should make the proper investigations of the builder before the contract is awarded.

The owner may be a large real estate operator and developer and may be his own builder. Then he does the work himself, making contracts only with subcontractors and material men,

or else he may have two corporations of his own, one a real estate company and the other a building company, and a contract is then drawn up between these two organizations. In New York and other large cities, many real estate operators carry on business in this manner and erect office buildings and apartments. Their structures are financed, in part, by corporations that sell mortgage bonds to the public, and thus a contract is made governing the advancing of such money between the owner and builder and the bond-selling company. Some title companies and other financial corporations advance money to owners in this way, and builders should know of these contracts that affect his work. Money is frequently advanced upon the cheaper classes of dwellings in this manner, actual payments being made at certain stages of construction, as when the first-floor joists are placed, when brick walls are completed, and so on throughout the life of the job. The builder, knowing these facts, can make arrangements in his contract to collect accordingly.

The owner may be a governmental body, a corporation, a firm, or an individual.

3. The Architect.—If the architect is employed by the owner only to draw the plans and specifications for a building, then the contract is made with the owner directly, and the builder will have nothing to do in the way of business with the architect—in fact, the latter may be unknown to the builder—but if the architect, as is the general rule for structures of any great cost, is likewise employed for supervision by the owner, then he becomes the agent of the owner and may act for him in every way, even to making and signing the contract, though, in most cases, the owner signs the contract with the builder, this being the safer course for the builder. The contract should set forth the duties and powers of the architect, but if this is omitted, then the architect will have such powers and duties as are customary in that section of the country and more specifically set forth in the ethics of the local association of architects and the American Institute of Architects.

The architect furnishes all plans and drawings, except such working drawings and plan specified to be furnished under the provisions of the contract, by the builder, his subcontractors, and material men. He alone can authorize and sanction changes either in the plans or in the specifications, and no one has authority to order supplemental or extra work done save the architect. He is supreme, save that he cannot usurp, even if the contract provides for it, the functions of a court at law.

Payments according to the contract are made upon his certificate, and supplemental agreements as to additional work and prices are made through or by him. All bills for extras are audited and checked by him and must bear his approval to be paid, unless the forms of contract to be given later provide for other auditing and approval. There are many forms of contracts under which building work is done. Subcontracts can be made only with the approval of the architects, and this is generally specific in the contract, as being approved in writing, but in many cases this clause is more honored in the breach than in the observance.

4. The Engineer.—Occasionally, some large industrial corporation does not employ an architect but has its buildings planned and erected by its engineer. In such cases, the engineer takes over the duties and powers of the architect, but more economical results are obtained by employing both an architect and an engineer and coördinating their work. This practice is replacing the old one of simply having an engineer. The contract must then set forth who is in charge, the architect or the engineer.

For most large buildings, there are generally employed a number of engineers to assist the architect. Thus, there may be an engineer for foundations, for structural steel or concrete, heating, lighting, ventilation, and other purposes, or one engineer may cover in his work several of these items. Many large firms of architects now employ engineers on their personal staff to do this work, but in most buildings these various items, including plumbing, are turned over to so-called consulting engineers, and these are paid, in most cases, by the owner; they make up the plans and specifications for their own particular lines of work from schedules and general layout plans furnished by the architect.

Such engineers supervise and pass upon the work of builders or subcontractors who come under their jurisdiction, but the architect must approve their work as well as the construction done. Decisions are made by these engineers, but in cases of disputes and changes, the architect's decision is final, and the engineers must, like the builder or his subcontractor, be guided by him. The contract should cover such matters in an explicit manner.

5. Day Labor versus Contracting.—When construction is carried on by day labor, instead of having it done by contract, the owner, either directly or through his architect, employs a superintendent of construction, engages mechanics, artisans, and laborers through him; purchases tools, machinery, and materials; and with his own forces, paid by daily wages, builds the struc-

ture. This is supposed to eliminate the contractor's profit or fee. This would seem to be the ideal method, as all chance of disputes with the contractor or builder over contractural rights, specifications, changes in plans and quantities, and quality of work is prevented. The owner, through his architect, is at all times supreme.

The reverse of this generally happens. Expensive machines and many tools may have to be purchased, and later, when these are sold at the completion of the work, the loss sustained may more than equal the builder's profit, as the latter charges only a reasonable plant expense or depreciation, the machines and tools having a value to him for future jobs. Money is not always saved by renting costly machines instead of purchasing, as it is customary to make such a per diem charge, so that money received for a year's rental will equal the cost of the machine, and the renter must maintain the machine during the rental period. In addition to this, mechanics, laborers, and others, including the superintendent, not having any money interest in the job or even future employment at stake, are likely to do indifferent work; the job will drag; and the cost will be greatly increased over the work done by the same men when employed by a builder. This individual's living and profits must be made by saving materials and obtaining efficient work from his employees. His money is at stake as well as the owner's; therefore, the greater the saving effected by the builder the larger his profit. In purchasing materials and making subcontracts, a builder is likely to save money over an owner, as he knows where and when to buy and how to handle and keep subcontractors busy, which is an incentive to them to bid low upon his jobs. The savings accrue not to the builder but to the owner, as the builder obtains these low prices and figures before bidding and bases his proposals upon such estimates.

Thus, building construction performed by a contractor has proved to be cheaper (save in exceptional cases) than that done by the day-labor method. Then, too, the builder maintains a year-round organization of trained mechanics and thus can do a better grade of work than that accomplished by day-labor forces, which must be recruited by men out of employment. The architects and his assistants pass upon the quality of the materials and see to it that the builder does everything in a workmanlike manner and follows the specifications, condemning all poor work and, if necessary, compelling such construction to be done over. With day-labor forces, the specifications are frequently ignored, and poor work is covered up and skimmed over to prevent the owner from finding fault, or advantage is taken of his ignorance regarding construction.

The day-labor method thus leads to extravagance, prolongation of the work in order to hold positions, poor workmanship, negligence, and, at times, downright dishonesty, thus giving an indifferent quality of construction. The contract method means quickly finished jobs, as it is to the builder's interest to rush his work; the specifications are followed, resulting in first-class work, money being saved to the owner.

6. Public and Private Contracts.—Contracts made with a national government, a province, state, county, city, town, or village are known as *public contracts*. Bonds are demanded on such contracts, and the contractor and his bondsmen are compelled to complete a job no matter what pecuniary loss they may sustain. No one under the law has the right to change the contract clauses or the specifications, which must be lived up to by the contractor. The worst possible features of the work may be forced upon him at any time. For these reasons, work done under public contracts can seldom be performed so cheaply as that under private contract.

Private contracts are those made with corporations (other than public ones), firms, and individuals. Bond may have to be given for such contracts, but the owner can recover only by suing the contractor and his bondsman. The architect can change the contract and specifications by agreement with the contractor, as nothing is as binding as on public contracts. This makes it possible to estimate more closely on such construction and yet do as good work.

Some contractors confine their operations to public contracts, while others take work only under private contracts. A third class does both kinds of construction.

7. Laws Preliminary to Contracts.—On both public and private contracts there are laws and procedure that are applicable to those stages that precede the making of a contract. These cover oral agreements, proposals, bonds, plans, specifications, guarantees, certified checks, and many other details. A builder should be conversant with this procedure, and although he can obtain books upon such subjects, it is advisable that he retain a competent attorney to guide him in such matters, especially if there are any subjects upon which he may feel doubtful.

8. Law of Contracts.—Both builders and architects should understand the law of contracts and the underlying principles. There are two fundamentals of all contracts. (1) The minds of the two parties to the contract must meet and agree upon a common understanding. ***This is done by a proposal plus an acceptance based upon the plans and specifications for a building to be erected upon a given site.***

This can be accomplished by either an oral or a written agreement, but in both cases there should be witnesses to the agreement. Oral contracts can always be disputed; written contracts cannot be so easily disputed; for this reason, written contracts are preferred and have a better standing before courts of law. A man's word may be his

bond, as the saying is, but his money posted or a written bond or contract is better security. (2) When a written contract is signed, properly witnessed, and sealed, then this supersedes all oral agreements, verbal conversations, and letters that led up to the making of the contract. These things can never have any bearing upon the contract unless a fraud has been perpetrated, when such matters can be reviewed to illustrate how advantage has been taken of one party to the contract, in order to set aside the written contract and have justice rendered between the parties. Books, too, are obtainable upon the law of contracts, but the safer course is to have a lawyer who is an expert upon building contracts. Written contracts for buildings are drawn up in many forms, and each will be considered under its title or proper designation.

9. Forms of Contracts.—There are many forms of contracts used for building construction. Under most of these forms, it is first necessary for the builder to make a proposal to the owner through the architect. This proposal for some forms of contracts, especially on private work or for subcontracts, may take the form of a letter. When this kind of proposal is made, the offer must be made up with great care and worded so as not to be ambiguous; otherwise, the contractor may be offering to do more work than he has estimated, and the other party, in accepting the proposal, may think that the contractor is offering to do the work as planned, thus leading to disputes.

Under many forms of contracts and for nearly all public contracts, a proposal form is used, and to make the proposal formal, it must be made out on the official form and followed as actually outlined. To deviate from the form means to make the proposal informal. No one has the right to consider an informal proposal unless it should be the only proposal entered, in which case an adjustment could be made. On public work, an architect has no right to consider an informal proposal, because it is not a proposal based upon the contract and specifications. Should a contractor desire to submit an alternate proposal or have some change made in the plans to save the owner money, he should first submit a formal proposal and then make his alternate on a separate form or sheet of paper. Should his formal proposal be low or be the accepted proposal, then the contractor can have his alternate considered, or all proposals may be rejected and new ones made based upon the change suggested in the alternate. Every contractor should be careful to see that his proposals are formal before they are submitted.

9a. Unit-price Contracts.—A unit-price form of contract is based upon the naming of unit prices for each kind and class or work to be done upon a building. By this method the exact amount of each class of work need not be definitely known if only the different classes and kinds of work are known. With a price set for each unit, it is then possible to carry on the job, paying the contractor only for the work actually done.

The difficult feature of this method of carrying on a contract fo. a building is the great variety of work that must be done and the difficulty of obtaining unit measurements for each item. Coupled with this, architects are loathe to take the time and trouble to measure up and keep a record of the various units. This form of contract is excellent for engineering construction but is not so well adapted to architectural work. It is necessary for contractors to estimate most construction upon a unit basis even when other forms of contracts are used, but the general preference for contract forms has been that of *lump-sum contracts*.

Unit-price contracts are still used, however, by some large corporations for building. The writer had recently to do with an industrial building project involving a cost of about $8,000,000,000, and all the work was done under this form of contract. One group of buildings that cost about $2,000,000 had 206 items in the contract. Of these, 44 items overran the preliminary estimate made by the architect, 59 items listed were not used, while there were 21 items of extra work, most of which were covered by a supplemental schedule of prices. The stacks for the boilers were listed as one item and sublet by the builder. The rough plumbing, the painting, and a few other classes of work were lump-sum items and sublet, but the builder and his subcontractor for plumbing were paid united prices for wash basins, toilets, and other items. The total cost of these buildings did not vary one-half of 1% from the architect's estimate. It was believed that the cost under a lump-sum form of contract would have exceeded the cost of the unit-price contract.

9b. Lump-sum Contracts.—Under a lump-sum contract, a price is figured by the contractor, who names a stated price or sum for a completed structure, according to the owner's plans and specifications. Thus, the owner and his architect depend upon the price bid and are not bothered with units or quantities, so far as estimating costs are concerned.

It is necessary that plans and specifications should be complete before proposals are asked, as any changes or alterations must be paid for as extras, or new prices must be agreed upon for the work. The contract upon this basis demands accurate and thorough work by the architect, the variations permissible being alternates asked for in the proposals.

The lump-sum form of contract has been the most common one used for some decades in erecting buildings. A variation of it has been to name unit prices for some classes of work for additions and deductions. Thus, for concrete foundations, the plans may call for the footings to be 20 ft. below the street level. The proposals made may name one price per cubic yard for any concrete to take the foundations deeper and a lesser price per cubic yard

for any deduction in yardage if the foundation is carried to a lesser depth than 20 ft. This would likewise apply to the excavation. It is possible to apply this variation in form of contract to any class of work having simple units; hence, the form of contract becomes a combination of the lump-sum and unit prices.

With a unit-price form of contract, the builder is not bothered by uncertain quantities of work to be done, as his work is measured up and paid for; but with a lump-sum contract, he must know accurately how much work is to be done. If plans and specifications are inaccurate and indefinite, then the builder must protect himself by naming in the price he bids an ample amount to cover extra work which he may be called upon to do or to cover possible changes for which he may not be allowed extras. Thus, the owner may have to pay more than he should for his structure, or if the builder does not estimate enough for such inaccuracies or discrepancies, then he is the loser.

9c. Cost-plus-percentage Contracts.—Due to the facts just outlined, the cost-plus-percentage form of contract has grown in favor during the past decade. Under it, the owner pays the cost of the work—that is, all materials, supplies, and labor. Upon this cost he pays the contractor or builder an agreed-upon percentage. Tools and machines are rented to the owner and figured in this cost of the structure. The percentage paid is supposed to cover the builder's own services, the knowledge and organization he brings to the job, and his profit.

Under this contract, every incentive is given the builder to do expensive work and run up the cost of the structure, for the larger the cost the greater will be the percentage paid him. Thus, a building estimated to cost $100,000 will net the builder more profit if he makes it cost $125,000. Many disagreements have occurred over contracts under this form, due to the belief that contractors have increased their cost purposely.

Under various forms of contracts it is still customary to pay for extra items, when a supplemental agreement is not made; or the contract provides for some special arrangement to pay for extra work, to pay the cost of such items plus a percentage. The costs consist of labor, liability insurance on labor, trucking or hauling, materials, and, if special machines or scaffolds are necessary and not used upon the rest of the work, a charge is made for these on a per diem basis. To these costs is added a percentage. Today, this is never less than 15 %, and for small organizations this per centage may give the builder a profit, but for larger organizations the builder should receive either 20 or 25 %. This is a matter for mutual agreement and should be incorporated in the contract. If a subcontractor does the extra work he should receive at least 15 % on the cost, and the builder should receive 5 % on the cost plus the subcontractor's percentage. This last item is never less than 5, though under some contracts it is 15 %. Percentage items always add to the cost of the construction.

9d. Cost-plus-a-fixed-fee Contracts.—To overcome this belief and also certain objections outlined under unit-price and lump-sum forms of contracts, the cost-plus-a-fixed-fee type of agreement has grown in favor with both architects and contractors. Under it the owner pays all costs as in the last-named form, but, instead of paying a percentage, he pays the builder a fixed fee previously arranged. To arrive at this sum, a general estimate of the cost is made, and with this as a basis, a flat fee is agreed upon.

No matter whether the actual cost is less or greater than the estimated cost, the contractor's fee remains unchanged. Under this form of contract, the architect may not even have started his plans when the builder begins his excavation. Thus, plans can be made as the work progresses, and unlimited changes can be made in either the plans or the specifications. The owner can purchase the materials or have the builder do so.

Many of the objections to other forms of contracts disappear under this one. The builder's reputation and his desire to obtain other work from the owner should cause him to do economical work, unless he is working at the same time on jobs based upon the unit-price or lump-sum form of contract. Then it is but natural for the builder to use his best men and machines upon the contract where he can save money and add to his profit and his poorest upon the contract in which his fee is fixed.

A prominent contractor who used this form of contract, and gave it great publicity by advertising in the leading journals of this country and Canada, found himself in the above predicament and so decided to give up bidding upon unit contracts, lump-sum jobs, and work done under other forms of contract and would not undertake construction except by cost-plus-a-fixed-fee contract. This is good business—namely, to have a form of contract and use it only. It gives confidence to owners and architects and allows a stable business to be built up, but it precludes the obtaining of public contracts when the law compels bidding to be done and awards the contract to the lowest bidder.

9e. Cost-plus-a-scale-of-fees Contracts.—There are two variations of the cost-plus-a-scale-of-fees form of contract. The prevalent one is to arrange a schedule showing probable costs and setting a scale of percentages or fixed fees to be paid upon the scale or schedule of costs. This was the form of contract used almost exclusively by the war department of the national government for the extensive program of construction carried on during the World War.

In these war contracts, the percentage or fee decreased with the amount of the contract increasing. Thus, for a schedule, the fee decreased several per cent for each $100,000 added to the total of the contract, until a maximum fee or minimum percentage was reached; then the fee remained the same even if several million dollars were added to the total of the contract. The greater part of the overhead was paid by the war department, and rental was paid for all machines and even for office fixtures, as typewriters, adding machines, etc. Office furniture was bought by the government, as were also small tools, so that, although the percentages or fees paid were small and the maximum fee was not large as compared to some contracts, $250,000 being the maximum fee, while some contracts amounted to more than $10,000,000 (2.5 % and less), yet the contractor or builder was able to make some profit.

A second variation of the cost-plus-a-scale-of-fees form of contract is that for which a fixed fee is set for an estimated amount of work, and then a rising scale agreed upon for each $1,000, $10,000, or $100,000 saved over this estimated cost and declining scale for each $1,000, $10,000, or $100,000 expended over the estimated cost, naming, however, a minimum fee that is assured to the contractor.

With this form of contract the builder is penalized for running up costs, whether he is at fault or not, while he earns a premium by saving the owner money over that of his architect's estimate. The greatest difficulty is in arriving at an estimated cost of the work. This can be done by the owner's architect and the contractor's agreeing upon an estimated cost. If these two cannot agree, they refer it to an arbitrator or board of arbitrators. If changes are made or extra work added, new estimates are agreed upon under supplemental contracts or by duplicating the original agreement.

9f. Cost-plus-a-bonus-and-penalty Contracts.—The second variation of the form of contract just described under Cost-plus-a-scale-of-fees Contracts is sometimes known as a cost-plus-a-bonus-and-penalty contract, so there is no need of further comment.

9g. Cost-plus-a-bonus Contracts.—In all cost-plus contracts, it is possible for the owner to offer a bonus for early completion, thus giving the builder a decided incentive to finish ahead of the contract time and thus add considerably to his profits. A bonus and penality for time limits will be considered under the heading Time Limits, Art. 15.

9h. Percentage Contracts.—The percentage form of contract likewise has two variations. The first one, used by some municipalities, is to have the architect make up an estimate of the cost of the structure. Contractors then make proposals based upon this estimate by bidding a percentage—as one contractor may bid 97% of the cost, another 100%, and a third 102%, the award being made to the one bidding the lowest percentage. This is also a variation of the lump-sum form of contract, as, in the end, the builder names a lump sum based upon the architect's estimate.

The second variation is that of a contractor bidding a percentage of the cost as a fee for which he is willing to build the structure. The estimated cost need not be known, and plans may be changed, for the percentage is paid on the final cost. Here the contract is awarded to the builder naming the smallest percentage. This form of contract varies from the cost-plus-percentage form only in the method of arriving at the percentage. In one, the owner and builder agree upon the percentage, while, in the last form, the builder bids and names his percentage in his proposal, the owner accepting the lowest-percentage bid.

In one form of the percentage contract, the owner furnishes the building materials, upon which a percentage is not bid, thus limiting the percentage on the labor items and the furnishing of plant, which is named as rental in the contract, but the percentage covers the cost of operating the plant, repairs, and all expenses. In this form of contract not only is the rental of plant named, but also the wages of all employees from office force and general manager down. The wages are supposed to be the prevailing rates of wages paid in that locality. If wages change, then a new schedule is agreed upon. The owner pays all of these costs plus the percentage bid. If there are any fees or expenses incurred in obtaining labor, the percentage is figured on such costs.

10. Prevailing Rates of Wages.—This term is now being used in many states in building contracts, and the provision covering it sets forth penalities for not paying such rates and provides for arbitration as to wages when complaints are made to boards and commissions having in charge public contracts. It means that union scales of wages must be paid by the builder, and in some states the higher courts have held the provision to be legal. This clause in contracts must be noticed and followed as far as possible in making proposals. There is no harm done the builder if he includes such wages in his estimates, provided the wages do not change during the life of the contract, but if a higher scale of wages is made after the work starts, he must pay such wages or there will be a breach of the contract. This is a possible injustice to the builder.

11. Parties to a Contract.—Naturally, there are two parties to a contract, and the builder is always one of these parties. In private contracts, the other party to the agreement is the owner. As a rule, the owner is the first party listed in the contract, while the builder is known as the second party. In public contracts, the first party to the contract is the government

making the agreement. The parties signing must be those set forth by law. These may be officials of the government or a legally constituted board or commission acting for the government. Such contracts must also be passed upon by the legal bureau of the government and may have to have the approval or certification of the financial department to show that the funds for the construction are available.

12. Certified Checks and Bidding Bonds.—On public contracts, a proposal must be accompanied by a certified check or a bidding bond from some bonding company to show the good faith of the bidder and his responsibility. As a rule, only one of these securities is demanded, and when a certified check is demanded it is sometimes possible to substitute a bidding bond. Some governments demand a certified check and a certificate from an acceptable bonding company stating that they will furnish the necessary construction bonds should the builder prove to be the successful bidder. Other states and cities demand only that a bonding company or companies be named as those willing to make the securities. Provisions are also made for accepting on deposit approved bonds, stocks, or other securities in lieu of a bond from a surety company.

Bonds are frequently necessary for private contracts, but, in many cases, builders are given work under one of the forms of contracts here listed and without bidding, but through the recommendation of the architect and inasmuch as such a builder may have satisfactorily completed a number of contracts for the architect, a bond is not used. This is becoming fairly common for many large structures, and the fact that work can be so obtained by a builder, and a bond saved, is a decided asset and means of obtaining work for a well-organized building contractor or company. Forms of contracts and bonds under such an arrangement are mere formalities; it is the confidence that counts and the fact that work will be done well and cheaply with small chance of any disputes, failures, or lawsuits, even should the leader of the architectural firm or contracting company die. This form of confidence and cooperation in building has a decided bearing on the entire subject covered in these sections on contracts and specifications.

13. Proposals.—As has been shown, this is the basis of agreement with the plans and specifications for making the contract. The making of a proposal, having it formal and making an alternate proposal, is covered in Art. 8 of this chapter. For private work there may be demanded little formality, as a letter is frequently used, but for public contracts a special form is generally provided. In making a proposal it is seldom possible to name a time limit for its acceptance, but for some public work statutes set the time in which the public body must accept the proposal. In case of a very low bid, advantage can, at times, be taken of such statutes. In very few cases and conditions can a builder withdraw his proposal for public work, as his certified check or bond binds him to accept award, but it has been done even without forfeiting the check or the bond.

If a proposal is not accepted by a private party within a reasonable time, then the builder can withdraw it by notifying the owner in writing that the proposal will be withdrawn if not accepted by a specified date. One builder doing much private construction withdraws all his proposals made upon jobs that are not awarded to him, so as to prevent a job's being thrust upon him later by the default of the successful contractor, after the work has been started, and he himself may be tied up with a number of new jobs. A proposal made and not withdrawn can be accepted at a later date when all conditions have changed.

14. Bonds.—Besides bidding bonds, builders have to make bonds for the faithful completion of the contract, the payment of bills, and to cover time limits. Comment was made upon such bonds in Art. 12 for both public and private contracts. Even where bonds are not demanded for completion, they may be necessary to protect the owner against injury to adjoining property, injuries to the public, patent royalties, infringements, and similar things. Some forms of construction and certain parts of a building may have to be guaranteed for a number of years, and bonds for such guarantees may have to be furnished. Some roofing companies have furnished such bonds through the builder to owners for some years. In such cases, the specifications of the guarantee company must be followed in that particular work. Most bonding in these days is done by surety companies, but personal bondsmen are sometimes used, they pledging real estate and other assets in making the bond.

15. Time Limits.—Time limits in private contracts generally date from the signing of the document, but in the public contract the limits start from the delivery of the contract, for some days or weeks may intervene between these two dates. The first time limit generally set is

that for starting the construction. This may be given as 10 days or 30 days, and in some cases there is a penalty for not starting, while in other cases there is no meaning in this clause except to delay the work and run into the possible penalities for slow completion. The contract may set a minimum and maximum time limit for starting, so that there may be some leeway in this matter.

The crux of any building contract is in the sections covering the payments, and next to this are those clauses covering the time limits for completion. Even this can be divided into two limits, that for occupancy of a part or all the building and that for final completion. It is common to start the paragraphs of these clauses, with the phrase: "Time is the essence of this contract." The time limit is given at time in days, weeks, months, years, or by a given date. When days are designated, Sundays, legal holidays, and, before the roof is placed, stormy days are not counted. for only working days can be considered, unless the contract specifically sets forth other methods of computing the days. Weeks, months, or years are considered as calendar periods, while a given or set date gives no chance for arguments as to the day of final completion. In building construction this time limit can mean much to the owner as well as the builder. The owner may have his building leased to one or more tenants and may himself be under a heavy forfeit to turn over possession by a given date. In one case of a building in New York City, a 26-story office structure, the forfeit for this possession is $5000 per week. This cannot be, or is not, made a part of the contract between the owner and the builder, but naturally it plays an important part in the building program and may be the cause of naming a penalty for slow completion by the builder. Reasons such as this one cause many owners and architects to select a builder upon whom they know they can depend and make a contract with him rather than attempt to save some money by taking competitive bids and let the construction to the lowest bidder. In some cases a contract covering fast completion and doing the work in less time than the contract, which the owner specifies, is made with the lessor, and a bonus scale on a sliding basis is named in such an agreement. The writer has had an experience of this kind in his own career and, besides this contract, covered some extra work of fitting up an office that was not included in the contract with the owner.

Time schedules are frequently made up as to the sequence of the work to be done and especially the letting and starting of subcontracts. In the past, such schedules have not been included in the contract, but this is now being done in a few cases. Such schedules—a sample is shown and discussed in another section of this "Handbook"—are made out by the contractor and approved by the architect, but some of the latter are now working up time schedules of their own and then coördinating theirs and the bidder's. Weekly conferences are held among the architect, the builder, and the subcontractors, and revisions are made in the schedule, and all are advised as to steps necessary to follow the schedule, so that time is saved by such coöperation. The legality of incorporating such schedules in contracts and enforcing them may be questionable, but if much used in the future, court decisions will be rendered that may change time limits on buildings.

Courts look with disfavor upon money payments' being named as penalties in contracts. To overcome this, the word is not used, but it is stated that a given sum is agreed upon between the two parties of the contract as liquidated damages for a given period of time for non-completion. It at once becomes evident that if $50 per day is agreed upon as damages, then every day saved must be worth that sum to the owner; so if the builder completes ahead of the specified time, the owner should pay a bonus of the same amount. Thus, if there is a penalty, there should also be named a bonus and of the same amount. So important is this subject of time limit for buildings that one method devised gives to the builder an increased compensation for saving time. This is being known as a "time limit with a rate for completion" and can be used under the cost-plus forms of contracts or a lump-sum agreement.

The builder is entitled to extensions of time for delays placed upon him by the owner or the architect, due to non-possession of land or part of the land, franchise or permits, plans, or changes and other causes. As these delays occur, written claims should be made for extension, even if they are not acted upon until later, for toward the end of the job disputes can occur over dates and other details, while a record at the time puts these matters beyond argument. In public contracts this is especially important, as contracts exceeding time limits may become illegal and void unless an extension is granted and for good and sufficient reasons.

16. Payments.—As already stated, this is the most important thing in the contract, and the method of payment and amounts must, to some extent, depand upon the form of the contract.

In public contracts the builder may have little to say or do about arranging for payments, as the law may govern this; otherwise, those officials in charge will have the contract drawn and the method of payments decided upon. For contracts for private work the builder may and should be able to make arrangements for payments to suit his financial needs, and it is possible to have such payments made as to carry the job almost to completion after the first payment is received.

In unit-price contracts, payments are generally made monthly, and a certain percentage is retained until completion. In lump-sum contracts the same arrangements can be made as for unit contracts, but this is not so advisable for the builder. If he does not prefer weekly or monthly payment, he can have the date of each payment stipulated, or provisions can be made for payments as certain stages of the work are reached—for example, a given percentage or amount when the foundations are finished, when the first floor joists are in place, or steel erected, or when walls are completed, and when the roof is on, and so on through the entire construction. In this way, it has been possible for a builder to receive, say, 75 % of the contract payments, when the building is only about half completed, so that the owner is providing money to carry on the job.

Under the cost-plus forms of contract and the percentage forms, the owner makes payments monthly or as the builder presents statements of invoices and payrolls due, so that the form of contract governs, to a great extent, the payment. Under these forms of contracts, however, provision must be made for making payments on the fee or percentage as the job progresses. Simple and plain agreements as to money matters make sincere friends and prevent disputes and lawsuits.

When a builder takes a mortage on a building as part payment, he obtains such cash as the owner has, by contract provisions, as soon as his work justifies such payment; then has the mortgage drawn and delivered by a stipulated date or when the building has reached a specified state of construction. This allows the builder to make preliminary arrangements of realizing on the mortgage and have the necessary cash to carry on the job. If the owner is placing a mortgage or is having mortgage bonds underwritten, the builder should advise himself of all the steps in this procedure so as to know just what chances he will have of receiving his money when due. Negligence in such matters may mean ruin to the builder.

Payments to Subcontractors.—It is as important to the builder that his subcontractors be paid as to receive payment himself. Advances may have to be made to some, in order to meet payrolls and buy materials. Such advance payments may have to be weekly, but, aside from these conditions, there is no more reason why a subcontractor should be made to wait indefinitely for his money than the builder. This is especially true of final payments to subcontractors. All of these matters should be covered by contract agreements or set forth in letters, and a specified time should be named for final payment. If a sum is to be held for a certain period as a guarantee or for similar reasons, this should be provided for in the agreement, and the rest of the money due paid promptly. There have been many abuses in this connection, and cases have occurred where payment has been deferred for a year after the building has been completed.

17. Retained Percentages.—This subject has been mentioned under Art. 16. Deduction of retained percentages are no longer made on all building contracts, but all provide for the final payment's being held up until after the building has been completed and accepted. This is especially true for private contracts. A reason for this is the fact that bonds are frequently used for building construction, so that the owner is, in a measure, protected without holding back part of the builder's earning. Forms of contracts have had much to do with ignoring retained percentages, for, by many forms, the owner and the builder are, for the time being, partners in constructing the building, the owner furnishing, to a great extent, the funds and, through his architect, the plans and specifications, while the builder furnishes some money, the necessary plant, and the labor organization.

When percentages are retained, there is no reason to continue it throughout the job, but a sliding scale can be arranged. A larger percentage from each payment until the total amount retained equals 10 % of the bid price. Then 15 % is added to each payment until the amount retained equals 5 % of the bid price. After this, 100 % of each payment is made until the final estimate is paid, when the 5 % retained is paid to the builder. This is a decided improvement over the old method and is fair and equitable to both parties. Provision should also be made to allow the builder to withdraw the cash held as retained percentage and substitute for it agreed-upon securities. This gives the builder his cash, and, at the same time, he is drawing interest upon the amount held as retained percentage.

18. Terminating Contracts and Breaches.—Every contract should have a clearly set-forth provision as to how it can be terminated with fairness to both sides, should the necessary conditions occur to cause the work to be terminated before completion. This is not possible in public contracts but is in private ones, although there are few cases where contracts are so terminated, except in case of the sale of the building.

Breaches are not desirable but come at times. Failure on the part of the owner to make payment as per the contract is a breach. Failure to furnish plans can be a breach. Delays on the part of the builder can be a breach, and other things provided in the contract, as assignments etc. In these matters, both the owner and the builder should consult their attorneys.

19. Signing Contracts.—Contracts should be signed with great care and consideration and in the proper legal manner. Public contracts must be signed by proper officials provided by statute, ordinance, or enabling acts and should be attested and have the government seal and, when necessary, carry the signature and seal of a notary upon it, with the proper certificate that the notary has been duly appointed and that his term has not expired. The builder's signature should be sealed and witnessed, and, if the contractor is a corporation, the proper

officials must sign, and the secretary affix the corporation seal. All the members of a firm should sign a contract. For private contract, the owner signs, and if the owner is a corporation, the same rules apply as to the builder's corporation.

It is not customary to have construction contracts recorded upon public records, as with clerks of courts etc., but this is not unwise, and in some cases today it is being done, especially when mortgages are made in part payment. Naturally, the mortgage should always be recorded in the local land-record office. Care must be exercised in signing contracts to conform to the statutes as to corporations that are not chartered in the state where the building is to be erected and as to foreign corporations being registered with the Secretary of State or other proper official or registering office. This can cause trouble as to the legality of a contract and also fines for doing business without being domiciled.

20. Supplemental Contracts.—Construction contracts should never be changed, but if they are to be modified as to prices or other conditions, supplemental contracts or agreement should be made and signed as a contract is, and this agreement attached to the original contract. Such agreements can be made by letter, but this may lead to trouble. For public contracts, such supplemental agreements can be made only by public bodies adopting a legal resolution authorizing such an agreement. Such resolutions are passed at the request and approval of the architect.

21. General Contractor.—The builder awarded the contract for the complete structure is known as the *general contractor*. He is the one to whom the owner looks for results. At one time, it was always customary to award the entire contract of wrecking old buildings, making the excavation, placing the foundations, and erecting and completing the building to the builder as a general contract, and although this is done today in the majority of cases, and more especially for smaller types of buildings, yet the practice is gaining ground of dividing up the work into several contracts, especially when specialists are needed for parts of the construction on very large undertakings.

For instance, a large office building may have pneumatic foundations or some other special type of deep foundations. Then the contract is first let for the wrecking of the old buildings occupying the site; with this may be included the excavation, or it may be made a separate contract. The foundations may be let to a specialist in that line, or this may even be divided, if concrete piles are used, by letting the pile work as one contract and the rest of the foundation as another contract. Then the rest of the work is let as a general contract to the builder. In case of industrial buildings, the furnishing and placing of machinery is frequently let as a special contract, as are high smokestacks and other special parts of buildings.

Some builders are also beginning to specialize in particular types of buildings. As already stated, a few confine their work to public buildings. Some builders, due to limited capital and experience, confine their work to buildings costing not over a certain sum of money; others may build industrial plants or buildings; such builders will often do engineering as well as architectural construction. Other companies build apartment houses or hotes only; others, banks and monumental buildings; other builders erect only theaters; and some undertake only contracts for office buildings. A large number of builders confine their work to stores or garages, and there are many builders who erect only dwellings. Even these are divided into several classes, as to cottages, bungalows, rows of dwellings, expensive houses, and the like.

Some of the largest building companies, in order to save having independent contracts made for parts of the construction and likewise to save the use of subcontractors, are establishing various building departments, under competent heads having experience in the various lines of work. In this way, the general contractor is placing foundations, doing concrete construction and brickwork, plumbing, plastering, painting, and other classes of building construction. There are many advantages in this, besides building up a strong contracting organization. The common practice, though, is still to let subcontracts, as they are, for most builders, decidedly advantageous.

22. Subcontractors.—The general parts of buildings sublet are the foundations, brickwork, steel construction, metal work, such as cornices, skylights, etc., plastering, painting, plumbing, and heating, electrical work, elevators, marble work, stone masonry, tiling, roofing, and other special kinds of construction. Millwork and materials are always sublet unless the general contractor happens to be a dealer or manufacturer of such materials.

Thus, on a large building, there may be the general contractor and from 10 to 20 subcontractors. The owner knows the subcontractor only through the general contractor and, dealing with the subcontractor by the owner and his architect, comes through the general contractor. The general contractor is paid by the owner, and he, in turn, pays his subcontractors. The general contractor at his option demands a bond of the subcontractor and such guarantee as he must make to the owner.

Contract agreements generally stipulate that subcontracts can be made only with the approval of the architect. The form of contract used between the general contractor and the subcontractors will depend upon the form used between the owner and the general contractor. In most cases, it is a duplication of the form, as with a lump-sum contract; the same form is used with the subcontractor. A percentage contract is duplicated in the same manner, but, in such cases, the general contractor's percentage may be reduced upon the work done by the subcontractor. At times, even with a percentage or fixed-fee contract, the owner elects to have the subcontractor do his work for a lump sum, including in it his profit. He then treats such sum as the cost to the general contractor and pays him his fee or percentage upon it.

It is customary, except where the owner furnishes all materials, for each subcontractor to furnish the materials he uses: thus, his prices cover both materials and labor, as do those of the general contractor.

23. The Makeup of a Contract.—There are many forms used in the making up or writing of a contract: some are gotten up as a pamphlet or book; others, in the form of a legal brief; others consist of a set of typewritten pages blueprinted and fastened at one end; while short contracts may be in the form of a letter. There is always a demand from some professional men for a standardization of any kind of document, as to shape, size, and even its typographical makeup and appearance. This may be desirable, but there are many reasons why architects are not likely to adopt such a standard. One is the cost, especially for small jobs and contracts, while the main reason is the loss of the architect's individuality in any standardization. A reputable and successful firm wishes to distinguish itself from others by the character of the work that comes from its office, and this is as true of a written contract and specifications as it is of drawings and plans. Each architect should have a standard of his own, but it need not conform to that of another.[1]

The makeup or form for a public contract will vary somewhat from that for private work. The latter need not be so elaborate, nor need it be hedged around with so many legal restrictions, but both should be drawn up in legal form and so that all provisions will hold under the law. The following general form can be used for any of the contracts listed in this book, or from the outline or memorandum given a standard form of contract can be devised.

The Title.—The first preliminary is to select a title for the contract which is descriptive of the owner and the building or buildings.

The Cover.—This may have on it the title and the name of the architect and may be simple or quite elaborate, giving individuality to the contract and serving as an advertisement for the architect. If the contract is in book form, the next page is the title page and is generally a repetition of the wording on the cover.

Copyright.—On the reverse side of the title page, the date and ownership of the copyright of the contract and specifications may appear if the architect wishes to protect his work by copyright. A copyright may be obtained from the Library of Congress at Washington by depositing two copies of the contract and paying a fee of $1.

Photographs.—The next pages may have on them picture elevations of from one to three elevations of the completed structure. This is not absolutely necessary but adds much to the appearance of the contract and is a mark of distinction. These elevations may be reproductions from wash drawings or pen or pencil artist's sketches.

Invitation to Bidders.—Upon the next pages should appear the invitations to bidders. If an official advertisement is published in any paper, a copy of it may appear on these pages, but as on many private contracts such advertisements are not used, only a general invitation is set forth stating the time and manner of receiving proposals. Attention can be called to this by letter to such builders as the owner and architects desire to bid upon their job.

Information for Bidders.—Under this heading a short description of the work is given; a list of drawings to be furnished the bidders, the general time for completing the contract, the security and bonds to be made, the qualifications of the bidders, and the acceptance and rejection of bids.

The Proposal.—The next should be the proposal. A memorandum should set forth that bids will not be received or considered informal, unless submitted on the proposal form. If it is desired, the page or pages of the proposal may be perforated sheets, so that they can be detached and submitted separately. It is good practice, however, to have the proposal bound in the contract so that it will be returned as part of the agreement and then make a complete document. Ample room should be provided to allow for signatures and seals of corporations as well as to give information as to those interested in the firm or corporation of builders. Should alternate prices be asked, space should be provided on the proposal form and, also, there should be sufficient room left for the builder to make an alternate tender if he desires. For other information, see Art. 12 of this chapter.

Bonds.—Following the proposal should come information regarding bidding bonds, certified checks for bidding, bonds for completion to cover guarantees, patent infringments, damage to property, and other bonds that may be demanded (Arts. 11 and 13).

Survey.—Here it should be told who is to make the survey of the building lot, if a survey has to be made; who is to pay the cost; and who is responsible for drawing up the necessary certificate.

Contract Proper.—The next thing should be the contract form and all the articles, paragraphs, sections, and clauses that have any bearing upon the contract of the work, other than the specifications. This should be as short

[1] A standard form of contract adopted by the American Institute of Architects can be obtained for a small fee. Address, The Octagon Building, Washington, D. C.

as possible, yet brevity should not be at the expense of being explicit and definite. It is advisable that all articles, sections, and pages be numbered to admit ready reference.

I. Intent and Purpose.—The first article should be in legal form as to the agreement or contract made and the intent and purpose of the contract. The parties to the contract are named and identified as to legal standing, especially in public contracts.

II. General Provisions.—Under this heading and article, there should be a general description of the scope of the work, and, by a series of subarticles, everything pertaining to the contract to follow should be defined.

Principals.—The parties to the contract are listed, their responsibility one to another is shown, and by definitions it is indicated how they will be referred to in the contract. For instance, the No Name Manufacturing Company will be known as the *owner*, the General Construction Company will be known as the *builder*, and Smith and Smith as the *architect*. Definition and status are given of others who may have a part, and the pronouns, abbreviations, and other definitions are listed.

Architect's and Engineer's Status.—The standing and responsibility of these parties should be set forth in detail.

Architect's and Engineer's Decision.—Under this heading is given the finality of the decision of these officials.

Builder, Superintendent, Foreman.—Here the standing of the contractor, of his superintendent, and of foremen is set forth; also, the statement that some responsible party must represent the builder upon the job to receive the orders and instructions of the architect.

III. Work to Be Done and Drawings.—The first subarticle under this heading will describe all work necessary to be listed in detail, and then a second subarticle will list all drawings and who is to furnish them and state that all must meet with the approval of the architects. A possible list of drawings may be as follows:

Architect's general plans and drawings.
Architect's detail drawings.
Contractor's plans for reinforced concrete.
Contractor's plans for workmen's utilities.
Mechanical engineer's plans for plumbing.
Mechanical engineer's plans for heating.
Lighting engineer's plans for lighting.
Electrical engineer's plans for electrical construction
Manufacturer's plans for boilers, etc.
Manufacturer's plans for pumps, machinery, etc.
Subcontractor's plans for elevators.

Others will suggest themselves.

IV. Prices and Payments.—The contract prices should be listed and should duplicate in terms and figures those submitted in the proposal. Next, the payments should be set forth, specifically as to amounts, how made, and when made. The final payment should likewise be provided for as to conditions and time. Reference should be made to Art. 15.

V. Retained Percentages.—When a percentage is retained, the amount should be given and when it is to be paid, and other money to be retained as guarantees should be set forth (see Art. 16).

VI. Additions and Deductions.—Here should be listed any payments to be made for additional work and deductions for doing away with guarantees of work or changes that will cheapen the job.

VII. Time Limits.—As already stated in Art. 14, this is an important article. Time schedules, limits, and everything pertaining to the time of completion as well as the starting of subcontracts and other details are included. Provision should be made for starting the work and for delays caused by the owner, the contractor, the subcontractors, the delivery of materials, and labor, as well as other delays, caused, for instance, by city improvements, etc.

VIII. Liquidated Damages.—Here penalties of various kinds for delays and other damages are provided for and listed.

IX. Liability of Builder.—Here are given those responsibilities and liabilities of the builder as to injuries to owner, architect, adjoining property, and other persons, both workmen and public, and provision is made for workmen's compensation insurance, accident insurance, fire and wind insurance, and other such matters.

X. Owner Secures Builder.—In this article, the owner secures the builder against injunctions and other defaults upon his part.

XI. Breaches of Contract.—This tells of breaches by both parties of the contract and how to prevent them.

XII. Extra Work.—This article describes what shall be considered extra work and how payment should be made.

XIII. Subcontractors.—Under this item are set forth how subcontracts may be made, the approval by the owner and architect, and their status (see Art. 21).

XIV. Contracts for Materials.—This is an important article on all percentage and cost-plus contracts. Who is to make the contracts should be set forth, and the care and responsibility for the materials until used.

XV. Inspectors and Inspection.—Cover all inspection and give the status of inspectors.

XVI. Changes in Plans and Work.—This provides for changes in plans and work and how the cost is to be covered.

XVII. Miscellaneous Provisions.—Here may follow a number of items that should be covered in the contract as subarticles.

Permits.—Tell who is to obtain and pay for all permits, ordinances, etc.

Leins.—Cover how the owner shall be protected from liens.

Royalties on Patents.—Set forth who shall pay these and the protection of each party.

Use of Premises.—Tell how the builder may use the owner's premises and the care that must be taken of the property.

Cleaning Up.—State that the builder must keep the property clean, keep down fire hazards, and hand over the building swept clean.

Workmen's Utilities.—List the utilities to be furnished for the workmen and state who is to pay the cost.

Sanitation and Drainage.—Cover temporary sanitation and drainage until the job is finished.

Temporary Connection With Pipes, Etc.—Tell how these must be made and at whose expense.

Office.—State that the builder must maintain an office on the job equipped with telephones and that plans and specifications must be kept on file in this office.

XVIII. Terminating Contract.—Tell how the contract can be terminated.

XIX. Assignments.—Cover assignments of contracts and subcontracts.

XX. Arbitration.—Indicate how disputes are to be settled by arbitration (see Art. 31).

XXI. Execution of Contract.—Space is provided for the date of the signing, the placing of seals, and the witnessing of the contract, also for the appearing before a notary, if necessary.

Form of Bond.—After this should be written the forms of bonds to be made and used by the builder.

Form of Subcontractor's Bond.—This covers the form to be used for this purpose.

Specials.—Additional articles can be added to any contract to cover machinery or any special item.

Specifications.—The specifications are covered in another chapter of this book. They follow the bond and contract.

24. Contracts for Wrecking Buildings.—In erecting many new buildings in towns and cities, one or more old buildings must be torn down or "wrecked" in order to make space for the new structure. Thus, the wrecking of buildings has become a great industry, and either builders themselves do this wrecking or it is done by wrecking contractors, who make a speciality of this work. Some of these contractors call themselves "wreckers and shorers," as they undertake contracts to move buildings, wreck them, and shore and underpin them, although foundation contractors also do the last two classes of work. To show the extent of the wrecking of buildings, it may be stated that in New York City, metropolitan district, for some years there has been wrecked annually an average of 10,000 buildings. In the Baltimore fire, considered a great calamity, less than a third of this number of buildings was destroyed.

Forms of contracts for this class of work vary from those used for erecting buildings. There are three distinct things to be covered in the contract—the price paid and to whom, the ownership of the materials salvaged, and the elevation at which the wrecking ceases as well as the disposition of the débris made.

Many contracts are made by letters offering to do the work and stating the basis covering the three points mentioned, and acceptance is made by a letter from the owner. For more extensive jobs or for public work, a regular contract is made. The following are the different bases of making such contracts:

The wrecker bids a price for the privilege of taking down the building and taking possession of all materials as the building stands at the time of receiving proposals. The job is given to the *highest* bidder.

The wrecker is paid a price for taking down the building, the materials remaining the owner's and being placed, after salvaged, where he designates, or the wrecker is paid for the job and pays a price for the materials. The job is given to the lowest bidder in these cases, consideration being given to the price paid for the materials.

The wrecker takes down the building without money's being exchanged between him and the owner for the materials the building contains, he paying the cost and making his profit from salvaging the materials.

In other cases, where the owner receives part of the materials—say, the bricks—he pays the wrecker for the work, and the latter takes such materials as are not reserved by the owner.

The usual practice is to wreck the building to the sidewalk or ground-surface elevation, leaving the foundations to be taken out with the excavation. If the walls are to be wrecked to the foundation level, this must be specified, as it is considered exceptional and not according to ordinary practice. Unless it is specified that the wrecker is to take away all débris and trash, he hauls away only such débris as interferes with his work, leaving the rest in the cellar or basement so that none of it is higher than the sidewalk elevation. This is customary, and to have the cellar left clean it must be so specified in the contract. If dust is to be prevented and laid by means of water or chemicals, then this stipulation, too, must be expressed in the contract, and a sum named as liquidated damages for complaints regarding dust, ignoring other property.

There is but a limited value to second-hand building materials, depending upon the trouble in finding purchasers. If all such materials could be sold promptly without rehandling and storage, good prices might be attained and a fair profit made, but only on a few kinds of material is this possible. Bricks, as a rule, bring a fair price and find a ready sale, yet there are always many "bats" that are useless, and, in some sections, in old buildings many bricks in the interior of walls are the old type of salmon or soft brick, which are useless and not worth cleaning. Besides brick, second-hand building materials, etc., obtained from wrecked buildings that possess a fair value are structural steel, plate glass, modern plumbing fixtures (old-style fixtures must be sold for junk), lead, brass, heavy timbers, and special high-grade hardwoods, boilers, tanks, and machinery. Also, metal window frames and some types of fire doors and shutters. The following materials have little value: stone and terra cotta, even ornamental, millwork, tiles, all kinds of roofing material, even slate, cast iron, and most pipe.

NOTE.—Reinforced concrete buildings have little salvage value and are very expensive to wreck. A contractor must get a large price for taking down a building built of reinforced concrete, and especially with columns, walls, and floors of concrete. Upon one occasion, two contractors who undertook the wrecking of a five-story building of this type abandoned the job, and the third man completed it on a cost-plus contract.

25. Contracts for Moving Buildings.—Special agreements are made for this class of building work, and risk of injury to the structure to be moved is, as a rule, thrown upon the contractor. A special contract is drawn up for this class of work, only two forms being used—the lump-sum contract or some variation of the cost-plus form. Remarkable jobs of moving, turning, and raising buildings to a higher elevation have been carried out by competent contractors in this class of work.

26. Contracts for Alterations and Converting.—In towns and cities, there is an ever increasing amount of altering parts of buildings, putting store fronts in old dwellings, and converting a building erected for one purpose to another use. The jobs entail some tearing or partial wrecking and small details of work. These items must all be included in the estimate and price. The forms of contract used for this kind of building are the lump sum, the cost plus, or the cost plus a percentage. In many cases, the work must be done while the building is occupied in part or as a whole, so that this may add considerably to the cost of the work. The builder must take into consideration all of these facts. Many builders make a speciality of this class of work, while there are a few who refuse to do any of it.

27. Quantities of Work.—In order to make up estimates of the cost of any building or structure, by either the architect or the builder, the quantities of the various kinds of work to be done must be taken off the plans. (It is possible to estimate roughly the cost of certain types of structures by applying a guess price to that area occupied, the cubical contents, or other rules. Accurate costs must be figured from quantities.)

Such quantities are taken off the architect's plans and from items mentioned in the specifications. The job is a tedious one and, for any size of structure, consumes much time. These lists are known as schedules. It would seem natural that the architect should be the one to make up such schedules, as he has had the drawings and plans made from his own design and has drawn up the specifications; consequently, he knows exactly what he has specified. In spite of this, the architect seldom makes up any such schedules; and, furthermore, he shifts the responsibility onto the contractor He goes even further and throws the blame for errors, omissions, and discrepancies upon the builder. Many quotations from building specifications could be given to show the position of architects in these matters.

It is in making up these schedules of quantities that the completeness and accuracy of the architect's drawings are tested. It is a surprising fact how few are complete or accurate, yet contractors are not in a position to protest, for, if they do, the architect simply drops such contractors from his list, thus depriving them of the privilege of bidding. These things are not only an injustice to the contracting profession but also likewise to the architect's client—the owner—for he is sure to pay more for his work when there are uncertain features about it. There is great need of reform in connection with these conditions of contracting. Although some blame can be placed upon builders, the greater part of it lies at the door of the architect who is unwilling to assume any responsibility or additional expense as long as he works for fees.

28. Quantity Surveying.—The act of making schedules of quantities is known as quantity surveying. If this survey is made up accurately and furnished to both the owner and to contractors making proposals, there is little question but that the minds of the two parties to the contract will meet upon definite and accurate information, making a closer and more economical contract than when the contract is based upon insufficient data.

This fact has been recognized in England and parts of Europe from which source the making of quantity surveys has been brought to us. It is now possible in some of our largest cities to get this surveying done by a third party. Companies are offering their services to owners and contractors to make these surveys, guaranteeing the quantities according to the plans and specifications so that any material or work that is not in the schedules is treated as extra work.

These schedules are not only used by the owner, his architect, and the general contractor, but also by the subcontractors. In many cases, they mean the saving of plans and the chance of obtaining more bids and greater competition, for subcontractors frequently cannot obtain plans if they are in distant cities or have not time to take off quantities, while, from the schedules, estimates can be made and mailed to the bidders.

There are a number of different methods being advocated to overcome the high cost each builder has for estimating on jobs. Quantity surveying is gaining favor, and there are a number of pooling agreements amongst subcontractors as well as builders. The steel manufacturers are among the leaders in pooling the cost to have but one estimate made for a structure. The time will no doubt come when but one estimate of quantities will be made for a building and the owner will pay for this as he should.

29. Extra Work.—All work called for by changes or not specified in the original drawings and specifications is termed extra work. As this was not included in the original price, it must be paid for as an extra.

There are two methods of paying for such work. One is by agreeing to a price for each lot of work, and the other is to do it by the percentage method—that is, cost plus a percentage—this last being the method in common use. Bills for such extra work must be rendered to the architect for his approval, after which they are paid by the owner. Disputes often occur over extra work because of the belief that many contractors swell the cost of the various items that go to make up the bills. For this reason, builders should give the owner every facility for checking up his bills, both as to materials and as to labor.

30. Construction Materials.—As a rule, construction materials are purchased by the contractors and are not paid for by the owner until they are put in place. Under some contracts, materials are paid for in part when delivered and are finally paid for as a whole after being placed.

In some cases, the owner purchases the materials, and the contractor stores, cares for, and places them. In both cases, whether purchased by the contractor or the owner, the contractor is held responsible for them.

If the owner purchases the materials, it is necessary for the contractor to charge a percentage of the cost to cover the storage, handling, insurance, responsibility of preventing them from being stolen, etc. If this is not done, the contractor is liable to sustain a loss upon that part of the work.

If the construction is being done under either the cost-plus-percentage or the scale-of-fees form of contract, the cost of the material, even when purchased by the owner, is used to calculate the fee or commission earned by the contractor, unless it be especially stipulated that the commission is figured only upon the labor costs. The general custom of the contractor purchasing the materials is the one favored by builders, and many contractors will not bid upon jobs for which the owners purchase the construction materials.

31. Plans and Specifications.—The plans and specifications are made up by the architect, except when a contractor agrees to get up plans and specifications for the owner in addition to doing the construction, thus saving the fees of the architect. This is not, however, a common practice except for small buildings, alterations, and work in the country on building barns and other farm structures.

For steel construction and concrete buildings, contracts generally specify that the contractor must furnish the detail working drawings, the owner furnishing only the general plan, loads, and such data, so that the contractor can have his details worked up. If this work is done by a subcontractor, the general contractor shifts the responsibility for these working drawings upon the subcontractor.

Owners and architects are not liberal in furnishing plans to contractors for estimating. They have lists, except for public work, of contractors whom they invite to bid and will not give plans to anyone except those on their lists. It is also becoming a common practice to make contractors pay for copies of plans or to demand a deposit of from $10 to $100 for a set of plans. This money is returned to the contractors, other than the successful bidder, when a bid is made or upon the return of the plans.

32. Arbitration.—Disputes will often arise over construction contracts, with resultant lawsuits. When such occur, highly technical subjects and the ethics of construction are carried before a jury and court that know little, if anything, of such matters; therefore, these things only become confused in their minds, and courts, instead of dispensing justice, dispense law. To overcome this, arbitration is being used in connection with suits over construction. Arbitration has no legal standing under our laws and before our courts, though in European countries it has. Contractors, through their various organizations, should work to have a legal status given it.

The advantage of arbitration over the courts is that men trained in construction listen to disputes and, knowing every phase of the subject, quickly see the injustice to one party and thus render a just decision. Time and expense both are saved in explaining technical subjects, as arbitrators chosen from the profession are familiar with such things.

It is possible for every construction contract to contain a paragraph setting forth that disputes must be settled by arbitration, stating the number of arbitrators and the method of selecting and paying them. Explicit rules can also be laid down for hearings and investigations so that every dispute may be handled promptly and gone into thoroughly. Each party to the contract should bind himself to accept and stand by the decision of the arbitrators. This is not legally binding, but it will, in most cases, bring satisfactory results.

33. Architect's Contracts.[1]—The architect for a building, except in cases where the architect is employed on a yearly salary, is employed by contract by the owner and is generally paid a commission upon the cost of the work, although, at times, a flat fee is agreed upon. Even if there is not a written agreement, an oral contract is generally made. Two services are covered

[1] Covered at greater length in Part II, Section 3, of this book.

in these contracts: (1) getting up the specifications and plans and (2) supervising the construction.

For some public buildings, large bridges, and memorials, prize competitions are held to obtain the best designs from architects. The first prize carries with it the prize money, payment for the plans, and supervision of the construction. The other plans submitted may secure prizes but nothing else.

Architects are also asked, at times, to compete in making plans, but inasmuch as this entails much work with little chance of compensation, few well-established architects will enter such competitions. In most cases, architects must depend upon their recognized ability, their experience, and their acquaintances to obtain jobs.

Some architects have a standard form of contract to use with their clients. Others set forth by letter to their clients what services they will render and their rate of compensation, the client accepting the offer by letter. Either method is considered a legal agreement under which an architect can recover. An architect who looks after his own contract with his client in the proper manner is likely to make the proper kind of contract with the builder in behalf of the owner and be fair to both parties.

SECTION 5

SPECIFICATIONS

By Daniel J. Hauer

Specifications, like drawings, are made a part and parcel of the contract, as they, with the money to be paid by the owner to the builder, are the basis on which the two minds have met and come to an agreement upon which the contract is framed, signed, and executed. The specifications can affect the contract, so that a decided change in them can make the contract null and void, yet in other than public contracts, the courts allow slight modification and changes in specifications. On public contracts, no one has the right to change, in any manner, modify, or evade the specifications. A public contract once executed, signed, and delivered precludes the changing of any part or clause of the specifications. This is not true of drawings and plans.

1. Specifications and Contract.—The specifications, as their name denotes, are those clauses of the contract that are grouped together explanatory of the drawings and plans, specifying the kinds of materials to use, the quality of such materials, and the class of work to be done. They likewise provide for the inspection, acceptance, and rejection of all materials and work. Specifications are as essential as drawings, if not more so, for with some simple structures dimensions can be incorporated in the specifications and the structure can be built without drawings. The oldest specifications in the world, yet concise and definite, were those given by God to Noah to build the ark that safely carried its precious cargo through the floods!

In most cases, the contract is bound with the specifications, and in public contracts this makes little difference; indeed, it is advisable, but it is not necessary in private contracts. Some contracts and specifications can be in the same cover, but it is possible for superintendents, mechanics, and others to be given separate bound copies of the specifications, omitting the contract. In this manner, in private contracts, the prices and payments can be kept secret, even the general form of the contract, which may have some effect on the workmen. If contract and specifications are bound separately, then in each there should be a reference to the other showing that they are a part of one agreement or document. It is also advisable, if the two are bound separately, for the owner and builder to sign the specifications.

2. Specifications should be Definite.—The first consideration for any specifications is to have them written for the job at hand and not copy them from some other job. Many architects do copy their specifications either from those prepared by others or from those used by themselves for other jobs. At times, some great misfits occur by this haphazard practice. Specifications covering frame buildings have been used for brick structures simply by adding articles on brickwork.

It is not necessary that every detail be written for each job. Brickwork and the general conditions governing it can be the same on every job; so it can be with concrete and woodwork; in fact, most of the general lines can be standard, simply adding the necessary things for each particular job. By this method, much work can be saved in getting up specifications. Under no circumstances should special clauses be inserted unless meant to cover the particular work to be done.

Then, too, all specifications should be definite; ambiguous clauses should be eliminated. Expressions such as "the owner will designate the style of fixtures" or "as the architect may direct" or "the number of panels will be designated by the owner or the architect" should be excluded. Decisions as to what is to be specified should be made before writing up specifications, and when this cannot be done, certain things should be provided for in a definite manner and also provide for an alternate. To be definite means to save money and secure the confidence of builders; it also prevents lawsuits. Specifications which are not clear add to costs and lead to lawsuits.

3. Standard Form of Specification.—There are no real standards for specifications. The same remarks made regarding standardized contracts are applicable to specifications. Large architectural firms employ men especially trained in specification writing. Smaller firms write their own specifications or else employ a consultant in this line. A demand is gradually coming

in the building industry for experts in specification makeup and writing. This is an indication of the importance of this subject.

4. The Specifications Proper.—The following memorandum in general form is given as guidance to an architect for writing up specifications for either public or private work. From it he can make such omissions as he deems expedient and make a standard to suit his needs. It is believed that the outline given is complete except for a few special types of buildings.

I. Introduction.—In this introductory, state that the specifications are part of the contract and that they with the drawings are intended to be full and comprehensive and describe, in a general manner, the work of the builder to make a complete building for the prices and payments covenanted.

II. Contract Drawings.—A list of drawings upon which the contract is based should be given as well as those showing typical details. For this purpose, all drawings should be numbered. A statement should be made as to furnishing, at set dates or time limits, the necessary working drawings and supplemental drawings. Cover here discrepancies between specifications and drawings and the decision of the architect regarding all plans and drawings.

III. Brief Description of the Work.—Give a brief description of the work and the class of construction expected. This can be short or elaborated upon for special jobs.

IV. General Clauses.—Describe here the intent of the specifications; the securing of permits and licenses; the plant to be furnished by the builder; the operation of such plant; the care of the building; the keeping of it open for inspection; the use of scaffolds; precautions against injury and loss by storms and fire; the care of construction materials; and all of those items that will not be covered under the other subheadings.

V. The General Manner of the Prosecution of the Work.—Here show the order and sequence of the building construction; the time of letting subcontractors and when these parties shall begin their work; the care to be exercised regarding adjoining property; the care of the public and the maintaining of traffic in the streets and roads; the time of turning over parts of the building, if this is necessary; the care regarding tenant, if an alteration job; and other details of the orderly carrying on of the job.

VI. Excavation and Backfill.—In these clauses of the specifications, cover the excavation of all kinds—earth, rock, quicksand, and other materials. The sheathing and shoring necessary must be specified and the need of pumping or unwatering the ground.

If borings or test pits are made before the contract is let, fairly definite information may be obtained upon which to base the depth of excavation and the type of foundation needed. Such information is valuable to the owner, architect, and builder, as a fair estimate could be made of each class of material to be excavated. These subsurface surveys are of importance and frequently prevent the payments of extras.

The backfilling under floors and around the structure, as to methods, should be specified. Foundations: First, a general description of the foundations should be given and the type to be used, as to pneumatic caissons, piles, grillages, etc.; the depth of the foundation from the sidewalk or curb should always be given on the plans and in the specifications.

Underpinning the foundation of adjoining buildings and shoring them temporarily is included in the clauses on foundations. The responsibility for this underpinning may be upon the builder, who must furnish plans for the methods to be used, but the architect should approve these plans. Under such conditions, the architect or owner cannot, without assuming responsibility, tell the builder how to underpin but can control the matter by not approving plans that are not, in the architect's opinion, satisfactory. If the architect is to furnish plans for underpinning, then he and the owner assume responsibility.

VII. Waterproofing.—This defines the type of water and damp proofing to be done and in what walls and floors. It is explanatory of the plans.

VIII. Cement.—Specifications covering cement should always be given before that for the different kinds of masonry. Under Construction Materials, more information will be given as to specifications and standards for such items.

IX. Concrete.—The principle uses for which concrete is specified should be told, the proportions, how measured, the method of mixing, the placing; likewise, the permissable aggregates, the kinds of sand, and the formwork should all be covered. For exposed walls, the finish is of importance and should be specified as well as all other details. Concrete is used for foundations, floors, and pavement, structural work, lintels, and sill and even for large stacks.

X. Mortar.—Here the specification for sand should be considered, and the kinds of mortar specified for each class of work, when mortar is to be used, as well as for pointing up. The specifications for mortar for fine brick, other special work, and size of mortar joints should be given for each class of work.

XI. Brickwork.—There are many kinds of bricks used in buildings and for a variety of purposes, as common arch brick, a variety of face bricks, including color schemes, brick for interior trim and finish, tile face brick, fire brick, insulating brick, and many other specials. The plans will show where some of these bricks are to be used, and detail drawings will show special designs and trim in brick, but the specification must give the rest of the information. The necessary bond in brick laying should always be covered in the specifications as well as the exposed corners of walls.

XII. Stone Masonry.—Here, again, may be a variety of classes of work to be described, as rubble, many kinds of ashlar masonry, ranged and broken rangework, point and bush-hammered dressed masonry, polished stonework, and others. The bond, joints, pointing, and dressing up the masonry must all be covered, and detail drawings and specifications must be gotten up for any carving of designs in stone. Stonework is expensive, and nothing should be left indefinite, even as to the size of the stone. The backing up with other masonry of stone masonry is of importance and should be governed by sound specifications to give a good bond.

XIII. Artificial Stone Masonry.—Under this heading must be told what make and kinds of such stone can be used, the test it is to stand, the finish and face it is to have, the method of laying, the bond, pointing, and other details.

XIV. Ornamental Terra-cotta Masonry.—The same general detail is used in Art. XIII must be followed under this heading. For special designs in both kinds of masonry, drawings must be furnished, and if the contractor or his subcontractors are to make up any special designs or details of such, the specifications should provide for the submitting of drawings or sketches covering such features for the approval of the architect.

XV. Terra Cotta.—Where terra-cotta tiles are to be used for floors, walls, fireproofing, or glazed tiles for coping of walls, the specifications should be divided into a number of subarticles, each one telling of the different uses and the details of the work.

XVI. Concrete Blocks.—This article should cover this class of masonry in a manner similar to those classes already discussed.

XVII. Chimney and Stacks.—Full specifications as to every detail should supplement the plans for such work, covering shapes and sizes of radial brick, fire brick, mortar joints, and all necessary work of construction. This class of construction is generally sublet, and provision should be made for it.

XVIII. Lumber and Millwork.—Although these materials still enter into the construction of many buildings, in fireproof structures their use is becoming almost obsolete, yet many articles made of metal are listed under the general heading and the subheads to be given. There are a number of grades of timber, lumber, and millwork, and so plans and specifications should be definite so as to obtain the desired quality and workmanship. Besides millwork, there are structural timbers, flooring (many grades), weather boarding, clapboards and ship-lap, shingles, laths, trim, and many specials. Under the subheads, will come

Doors.—These may be wood, metal, wood covered with metal, fire doors, and special cast doors.

Windows.—Frames and sashes can be of wood and metal, and there can be a large number of special designs and types. Fire shutters as well as other shutters are included with windows.

Stairways.—Besides wooden stairs, there are steel, concrete, a combination of the two, marble, tiles, etc. All should be specified and described and shown in drawings and writing.

Floors.—Floors are now laid of many materials, depending upon the use given them—lumber, concrete, marble, tiles, and various kinds of composition and patented floor surfaces. These last are generally guaranteed. All kinds should be carefully defined and made to conform to a standard, as floors have much to do with the interior appearance of a building.

Walls.—In some cases, the walls are covered in the plans and specifications in the structural details, but there are special walls, as light partition walls, fire walls, sound-proof walls; and the finish and appearance of all walls is important. Such should be set forth in the specifications.

Trim.—This item is in connection with the walls, stairways, and floor, referring mostly to interior work.

XIX. Roofs.—These are not only costly, but also the success of a building depends upon them. There are many kinds used, and the specification for each should be definite. In many cases, guarantees running from 5 to 20 yrs are made upon different kinds of roofing.

XX. Cornices.—These are built in connection with the walls and the roof and must be water tight as well as ornamental so should be fully covered in the plans and specifications. Detail drawings are generally made of the cornice.

XXI. Skylights.—These are generally a part of the roof and are now made of galvanized iron and, generally, wire glass. Careful attention must be paid to the construction and the specifications.

XXII. Structural Steel.—Under this heading comes an important item in the erection of high buildings andlarge industrial plants. There are commercial shapes used extensively in other buildings, as beams, columns, angles, channels etc., while there are fabricated shapes and invented members that are more or less made up from regular rolled shapes; then, at other times, there are special fabricated members and structures. The specifications should cover the loading of all such members, the tests as to tensile strength, and other engineering and architectural details.

XXIII. Construction Materials.—For convenience, all construction materials will be covered in this heading and other subheads, but in the regular specifications each material specified should be under a separate article.

Reinforcing Steel.—The kind of steel for reinforcing concrete as to shapes, tests, etc., should be covered, and also wire mesh, special forms, and other details.

Cast Iron.—Under this head may come structural iron, plates, and other kinds of cast iron.

Wrought Iron.—There may be brackets, fire escapes, porticoes, and many other uses for wrought iron to be described and listed.

Lead.—This metal is used for pipes and other purposes.

Tin.—Besides tin roofs, this metal is also used for flashing.

Copper.—This metal is used for some parts of roofs and for many other purposes, as store fronts, panels, and cornices.

Zinc.—This material is not used so much as formerly but sufficiently to be noted.

Galvanized Iron.—This is a metal, which, in spite of short life unless kept well painted, is being used more and more in building construction, for skylights, frames, flashing, fronts, ventilators, and other purposes.

For all materials, the specifications must cover the quality, the inspection and rejection, and the care of them until used. There are many national engineering and technical societies and trade associations that have adopted standard specifications governing the selecting and grading of most construction materials and work in connection with them. Some of the associations are national in scope, and some are sectional, and the latter are based upon the national organization but take into consideration local standards. This is the case in the lumber associations and the local underwriter's associations, under the national organization.

There are standard specifications and grading rules for lumber, cement, steel, electric wiring, fireproofing, stone, concrete, brick, most metals, boilers, and many other materials and items used in buildings. Among the organizations having such standards, besides the lumbermen's associations and the underwriters', already mentioned, there are the American Society of Civil Engineers, the American Society of Mechanical Enginerers, the American Institute of Electrical Engineers, the American Institute of Architects, the American Society of Testing Materials, National Brick Manufactures Association, American Concrete Institute, Cement Manufacturers Association, and many others. Besides this, many bureaus of the national government and the experiment stations of state universities and other educational institutions have collected much data as to standards and the strengths of materials, which can be obtained for a small fee. Such standards should be followed in the regular building specifications, but it is improper to copy these long specifications, for many builders are not accustomed to the special terms used in them, and they feeling uncertain, protect themselves by adding a percentage to cover any rejections under such specific specifications. Instead of copying such specifications, it is proper to mention them by name or state that certain provisions in them will be used, as those regarding lumber as set forth in the National Lumbermen's Association, or, for cement, according to the standard of the American Society of Testing Materials, making such specifications a part and parcel of those to be used. This can be done through a long list. Any architect or builder can obtain these standards and have them on file. Some are given in this "Handbook."

XXIV. Fireproofing and Fire Protection.—Although the plans will naturally show much in the way of fireproofing in building a fire-resistance structure, yet there are many things to be covered in the specifications, and the latter will give more details as to fire protection, both during the period of construction and when the building is finished. Walls, columns, floors, windows, and many other structural features must be fireproofed, and there are a number of different kinds of materials used for this purpose. Electric wire must be properly insulated and protected. Stacks and breeching must be considered, and hot pipes must be covered. All of these details must be set forth in writing.

For fire protection, the plumbing must be planned to care for sprinkler systems; pumps of large capacity must be installed to be started at short notice. A fire-alarm system is essential. There must be fire escapes and possibly lightning rods. Also, fire walls, fire doors, and shutters, and other protection measures. During building construction, water barrels and buckets should be on hand for emergencies, and if a building is to have a water tank for fire protection, specifications should provide for as early installation as possible of it, so that it will be of use during construction if it becomes necessary. Smokers will throw lighted cigars and especially lighted cigarettes around and out of windows. Such facts should be taken into consideration, and inflammable materials should be used where such things may happen.

XXV. Plastering.—This must be considered with fireproofing and the article to follow. Metal lathing are much more protection against fire than wooden laths. Specifications must tell of mortar to be used and the number of coats and especially white coating. Plastering must always be taken into consideration with the walls and ceilings, unless hardwoods or metals are used. Then specifications should be gotten up for these items.

XXVI. Sound Proofing.—In high-class buildings this item of construction is becoming of much importance, and just how walls and floors are to be made sound proof should be defined as well as the results to be obtained.

XXVII. Plumbing.—Definite specifications should always be used for this work, for there are many different qualities of plumbing. A time limit should especially be fixed for the time of starting and finishing the rough plumbing so as not to interfere with the progress of other work. Tests if needed and pressures for pipe and work to withstand should be specified, and the quality and type and style of fixtures should be explicitly designated.

XXVIII. Refrigeration.—Many buildings now have ice water delivered throughout them. This work may be included in the plumbing or, with other refrigeration, may be included in a separate contract. These things come in connection with modern office buildings, apartments, hotels, hospitals, etc., while theaters may have a ventilation system connected with a refrigeration plant. Then cold-storage warehouse and ice plants call for special specifications as to ammonia pipes and storage, and as to special cold insulation. Thus, there may be much to specify as to refrigeration, insulation, pipes, and tanks. With electrical operation, care must be takento damp proof against short circuiting of electric currents. Specifications must be carefully written regarding all phases of refrigeration.

XXIX. Heating.—This, too, may either be a subcontract with the plumbing or may be let separately. There are many details and items to be considered even after the type of heating is selected. Boilers, combustion, flues, pipes, radiators, size, and placing, and many other appurtenances. Even if outside heat is used, the specifications cannot be short and will take considerable space and a number of articles or subheads.

XXX. Ventilation.—This is a subject in connection with the heating, refrigeration, and even the plumbing. For school buildings, public halls, theaters, and hospitals, it is of utmost importance, but it is necessary in every type of building. Even the roofing contract may be effected by the ventilation system. There are on the market a number of patented ventilatory systems in connection with the heating system. It is a poor system of ventilation that uses only the doors and windows.

XXXI. Lighting.—Here is an item that must be considered with the general design of the building, and especially as to windows and doors. In the specifications the utility as well as the appearance must be considered. Plans will show outlets, but much must be told in the specifications. Aside from the general appearance of buildings, the first criterion made against architects is the lighting of the building and skylights, especially if the latter leak.

XXXII. Elevators.—This, too, is generally a subcontract, and outside of the general specifications, the subcontract frequently furnishes the detail of the specifications subject to the approval of the mechanical engineer and the architect.

XXXIII. Fire Escapes.—The specifications for these must conform to the building code and must tell of the type of construction, while the plans should show the location.

XXXIV. Building Hardware.—This heading is short, but it covers many detail items. The plans can tell little regarding the hardware; the specifications must tell.

XXXV. Mail Tubes and Chutes.—If these are necessary, clear specifications should cover them.

XXXVI. Telephones.—These too, if they are to be installed, should be covered by specifications telling where wires should go into each room and the location of the telephone.

XXXVII. Glazing.—This should specifically cover all glazing, plate glass, skylights, wire glass, stain glass, double strength, and, in fact, all glazing, including the fastening of the glass.

XXXVIII. Painting.—If a subcontract is made for this work, it generally includes the glazing, but in some cases the builder does the work with his own forces. The painting specifications should be given in detail, for although the plans can show the area to be painted, yet the specification must cover the number of coats, the kind of paint, and the quality. Paints are made for various materials, and each should be used for its special work, as for brick, concrete, stone, steel, iron, hot and cold, wood, galvanized iron, and other materials.

XXXIX. Tiling.—This is likewise work that is sublet, so that specifications should be definite and go into detail. Unless the architect furnishes detail designs, the subcontractor submits such for the architect's approval.

XL. Interior Marble.—Here the architect furnishes the details of the plans and design and the specifications, and the builder generally sublets the work.

XLI. Vaults and Safes.—This class of work is generally sublet as to safes and vault doors, and the architect's specifications may be supplemented by those of the manufacturer's, subject to the approval and rejection of the architect.

XLII. Transmission and Machinery.—When goods and other things are to be transmitted through a building, or machinery installed, then very definite specifications should be drawn covering the foundations to be used and the installation of the machinery.

XLIII. Specials.—There may be many other specials that may have to be covered by the specifications, such as water tanks, overhead cranes, railroad tracks, ovens, paving, esculators, and other items.

XLIV. Workmanship.—This is necessary and can be dealt with under the single article, or it can be put under each class of work as a clause; as, for instance, under steel, the workmanship can be set forth, and the specifications for rivets, painting, and all details of the labor that is to be performed. This is a necessity.

XLV. Signs.—Many signs are now used on buildings, as the owner's, renting agent's, architect's, builder's, subcontractor's and others. An article should be incorporated in every specification setting forth how signs are to be placed, who is to pay for them, and other details as to rights and priveleges to such signs or advertising.

5. Additions and Alternates.—Other articles and clauses as needed can be added, and room can also be provided for alternates furnished by builders, subcontractors, and material men.

6. City Codes.—All construction done in towns and cities must conform to city codes, and the plans must be passed upon by the city building inspectors. The building inspector also issues a permit before the work can be started. If a fee must be paid for this permit, it is customary for the owner to pay it, although under some contracts the builder pays it. In many cases, city codes give bearing power of soils for loads and many other regulations, so that the specification writer must take into consideration all the regulations of the building code. The builder, too, must know these things.

The builder must also conform to city ordinances regarding the safety of pedestrians and vehicles and those regarding the blocking and protection of sidewalks and streets. For this reason, sidewalks are sometimes covered two and three times for the same job by different contractors—a great waste of money that the owner pays. This should be prevented by the owner's having the work done once, and the protection's remaining until the building is completed.

7. Schedules of Materials and Work.—Following the alternates in the specifications, it is possible to give the schedules of materials as taken from the drawings and specifications. (Only recently the writer saw such schedules attached to the specifications.) This allows the contractor to know definitely what the owner and architect desire as to grades and qualities. It is also a check upon the plans. A builder can easily check up such a schedule from the drawings and specifications. Such schedules of materials also allow the contractor to obtain prices quickly while he is estimating on the job instead of receiving some prices after the proposal is submitted.

Reference has already been made as to quantity surveying. Such surveys would give not only the schedules of materials but also the work or labor schedules which, if made out, should follow the list of materials. These schedules would make the bidders have the same knowledge of the job as the architect possesses, thus allowing closer and more accurate estimates to be given.

8. Sheets of Specifications.—In writing specifications and having certain standards, it becomes possible to cover the main features of a job with these standards. Thus, most of the concrete construction can be standard, one job being similar to another; the carpenter work

can be the same; likewise floors, millwork, painting, glazing, etc. Now, if the specifications for each class of work or type of construction are written or printed upon separate sheets, and the various standards not run from one sheet or set of sheets to another, it becomes very easy to get up a set of specifications.

With the standard for each class of work printed upon one sheet or set of sheets, the material for the various kinds of construction can be taken from a file and placed together according to the arrangement given in this section or the order adopted by the architect. Thus, the greater part of the contract form and specifications can be compiled from sheets already written or printed. Blank spaces left on the bottom of these sheets or extra blank sheets placed in the specifications will provide ample room for writing out those details that must be special for each new job. In this manner, an architect's specifications will vary on different jobs only for those details that must be gotten up specially for each undertaking. Those architects who have tried this method consider it ideal.

9. Index.—If specifications and the contract are printed, both sides of the pages are used but if written, typewritten, or blueprinted, only one side of the paper is used. Whether long or short, the contract and specifications should have a table of contents or an index or both, so as to enable readily the finding of various provisions and articles. The table of contents is generally put among the first pages, following the title and copyright, while the index is the last thing in the book.

10. Onerous Specifications.—In concluding, it must be remembered that vague or indefinite conditions in a contract, and such clauses and provisions in specifications, especially for architectural construction, have as much to do with adding to the cost as impractical and poorly prepared plans. Contracts and specifications must be fair and definite if good work is to be done at a reasonable cost.

PART III

MECHANICAL AND ELECTRICAL EQUIPMENT

SECTION 1

HEATING, VENTILATION, AND POWER

By Ira N. Evans

PROPERTIES OF AIR, WATER, AND STEAM

1 Water.—Water is a chemical compound composed of 16 parts by weight of oxygen and 2 parts hydrogen, or 2 volumes of hydrogen to 1 of oxygen (H_2O). It is practically incompressible but its weight per cubic foot changes with the temperature (see Columns 1 and 6, Table 2). A U. S. gallon occupies 231 cu. in. and weighs, at 62 deg. F., approximately 8.33 lb., and 1 cu. ft. = 7.48 gal. The boiling point of water varies with the absolute pressure upon its surface —that is, every absolute pressure has a fixed boiling point. For example, 212 deg. F. is the boiling point for a pressure of 14.7 lb. The boiling point also changes with altitude above sea level due to the reduced atmospheric pressure. The following table gives the boiling point at different altitudes:

Table 1.—Boiling Points of Water at Different Altitudes

Boiling point (Fahr.)	Altitude above sea level (feet)	Atmospheric pressure (lb per sq. in.)	Barometer reading (inches of mercury)
185°	14,649	8.38	17.06
190°	11,800	9 34	19 02
195°	9,030	10 39	21 15
200°	6,304	11 52	23 47
205°	3,612	12.77	26 00
210°	1,025	14.13	28.76

The specific heat of water, or the number of British thermal units (B t.u.) required to raise the temperature of 1 lb. of pure water 1 deg. F., varies slightly with the temperature, but for all purposes of heating it may be taken at 1 B.t.u. per lb. Table 2 is a steam table which gives the boiling point for various pressures.

2. Steam.—Steam is a vapor which results from supplying sufficient heat to water to bring it to the boiling point and to cause it to evaporate. The change from liquid to vapor takes place at a definite and constant temperature which is determined solely by the pressure on the water. A change in pressure will always be accompanied by a change in temperature at which boiling occurs, and is accompanied by a corresponding change in the heat required to evaporate the water after it is brought to the boiling point, called *latent heat of evaporation.*

2a. Steam Table.—In Table 2, pp. 1145 and 1146, the gage pressure is given for various temperatures, with zero reading at atmosphere. The absolute pressure is the gage pressure plus 14.7 lb. The density is the reciprocal of the specific volume. The total heat is the heat in the liquid plus the latent heat of evaporation.

Below 212 deg. F. the pressure is tabulated on p. 1145, in inches of mercury, for use in solving problems dealing with condensing prime movers. The properties of steam are all tabulated for a weight of 1 lb. of saturated steam. The heat of the liquid and total heat are calculated above

Table 2.—Thermal and Physical Properties of Water and Saturated Steam

Marks and Davis

Temp. (Fahr.)	Vacuum (inches of mercury) / Gage pressure (lb. per sq. in.)	Absolute pressure (lb. per sq. in.)	Specific volume (cu. ft. per lb.)	Density (lb. per cu. ft.)	Weight of liquid (lb. per cu. ft.)	Heat of liquid (B.t.u.)	Latent heat of evaporation (B.t.u.)	Total heat of steam (B.t.u.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
32	29.74	0.0886	3294.0	0.000304	62.418	0.00	1073.4	1073.4
35	29.71	0.0999	2938.0	0.000340	62.425	3.02	1071.7	1074.7
40	29.67	0.1217	2438.0	0.000410	62.43	8.05	1068.9	1076.9
45	29.620	0.1475	2033.0	0.000492	62.425	13.07	1066.1	1079.2
50	29.560	0.1780	1702.0	0.000587	62.42	18.08	1063.3	1081.4
55	29.464	0.2140	1430.0	0.000700	62.395	23.08	1060.6	1083.6
60	29.40	0.2562	1208.0	0.000828	62.37	28.08	1057.8	1085.9
65	29.30	0.3054	1024.0	0.000977	62.335	33.07	1055.0	1088.1
70	29.18	0.3626	871.0	0.001148	62.300	38.06	1052.3	1090.3
75	29.047	0.4288	743.0	0.001346	62.260	43.05	1049.5	1092.5
80	28.891	0.505	636.8	0.001570	62.220	48.03	1046.7	1094.8
85	28.711	0.594	545.9	0.001832	62.165	53.02	1044.0	1097.0
90	28.503	0.696	469.3	0.002131	62.110	58.00	1041.2	1099.2
95	28.265	0.813	405.0	0.002469	62.055	62.99	1038.4	1101.4
100	27.994	0.946	350.8	0.002851	62.00	67.97	1035.6	1103.6
105	27.684	1.098	304.7	0.003282	61.930	72.95	1032.8	1105.8
110	27.331	1.271	265.5	0.003766	61.860	77.94	1030.0	1108.0
115	26.933	1.467	231.9	0.004312	61.785	82.92	1027.2	1110.2
120	26.482	1.689	203.1	0.004924	61.71	87.91	1024.4	1112.3
125	25.971	1.938	178.4	0.005605	61.63	92.90	1021.6	1114.5
130	25.40	2.219	157.1	0.006370	61.55	97.89	1018.8	1116.7
135	24.76	2.533	138.7	0.00721	61.465	102.88	1016.0	1118.8
140	24.04	2.885	122.8	0.00814	61.38	107.87	1013.1	1121.0
145	23.25	3.277	109.0	0.00918	61.29	112.86	1010.3	1123.1
150	22.35	3.714	96.9	0.01032	61.20	117.86	1007.4	1125.3
155	21.37	4.199	86.4	0.01157	61.10	122.86	1004.5	1127.4
160	20.27	4.737	77.2	0.01296	61.00	127.86	1001.6	1129.5
165	19.06	5.333	69.1	0.01448	60.90	132.86	998.7	1131.6
170	17.72	5.992	62.0	0.01614	60.80	137.87	995.8	1133.7
175	16.25	6.714	55.7	0.01796	60.69	142.87	992.9	1135.7
180	14.63	7.51	50.15	0.01994	60.58	147.88	989.9	1137.8
185	12.85	8.38	45.25	0.02210	60.47	152.89	986.9	1139.8
190	10.90	9.34	40.91	0.02444	60.36	157.91	983.9	1141.8
195	8.77	10.39	37.04	0.02700	60.24	162.92	980.9	1143.8
200	6.45	11.52	33.6	0.02976	60.12	167.94	977.8	1145.8
205	3.92	12.77	30.53	0.03276	60.00	172.96	974.7	1147.7
210	1.16	14.13	27.8	0.03597	59.880	177.99	971.6	1149.6
212	0.00	14.7	26.79	0.03732	59.83	180.00	970.4	1150.4
215	0.90	15.6	25.35	0.03945	59.755	183.00	968.4	1151.5
220	2.49	17.19	23.15	0.04320	59.630	188.10	965.2	1153.3
225	4.21	18.91	21.17	0.04723	59.500	193.10	962.0	1155.1
230	6.07	20.77	19.39	0.0516	59.370	198.20	958.7	1156.9
235	8.09	22.79	17.78	0.0562	59.240	203.20	955.4	1158.7
240	10.27	24.97	16.32	0.0613	59.110	208.30	952.1	1160.4
245	12.61	27.31	15.01	0.0666	58.970	213.40	948.7	1162.1
250	15.12	29.82	13.82	0.0724	58.830	218.50	945.3	1163.8
255	17.83	32.53	12.74	0.0785	58.690	223.56	941.9	1165.4
260	20.72	35.42	11.76	0.0850	58.550	228.60	938.4	1167.0
265	23.82	38.52	10.87	0.0920	58.405	233.70	934.9	1168.6
270	27.15	41.85	10.06	0.0994	58.260	238.80	931.4	1170.2
275	30.70	45.40	9.32	0.1073	58.110	243.90	927.9	1171.8
280	34.48	49.18	8.64	0.1157	57.960	249.00	924.3	1173.3
285	38.54	53.24	8.02	0.1246	57.805	254.20	920.5	1174.7
290	42.85	57.55	7.46	0.1341	57.650	259.30	916.9	1176.2
292	44.64	59.34	7.24	0.1380	57.586	261.30	915.4	1176.8
295	47.43	62.13	6.94	0.1441	57.490	264.40	913.2	1177.6
297	48.34	64.04	6.74	0.1483	57.426	266.50	911.7	1178.2

TABLE 2 (*continued*).—THERMAL AND PHYSICAL PROPERTIES OF WATER AND SATURATED STEAM

Temp. (Fahr.)	Gage pressure (lb. per sq. in.)	Absolute pressure (lb. per sq. in.)	Specific volume (cu. ft. per lb.)	Density (lb. per cu. ft.)	Weight of liquid (lb. per cu ft.)	Heat of liquid (B.t.u.)	Latent heat of evaporation (B.t.u.)	Total heat of steam (B.t.u.)
300	52.30	67.00	6.46	0.1547	57.330	269.60	909.5	1179.1
302	54.33	69.03	6.28	0.1591	57.264	271.60	908.0	1179.6
305	57.47	72.17	6.03	0.1659	57.165	274.70	905.7	1180.4
307	59.64	74.34	5.86	0.1707	57.099	276.80	904.2	1181.0
310	62.97	77.67	5.62	0.1779	57.000	279.90	901.9	1181.8
312	65.27	79.97	5.47	0.1829	56 932	281.90	900.3	1182.3
315	68.79	83.49	5.26	0.1904	56 830	285.00	898.0	1183.1
317	71.2	85.90	5.12	0.1956	56 762	287.10	896.5	1183.6
320	74.93	89.63	4.91	0.2036	56.660	290.20	894.2	1184.4
322	77.49	92.19	4.78	0.2092	56.588	292.30	892.6	1184.9
325	81.45	96.15	4.60	0.2176	56 480	295.40	890.2	1185.6
327	84.15	98.85	4.48	0.2234	56.408	297 50	888.7	1186.1
330	88.30	103.0	4.306	0.2322	56 300	300.60	886.3	1186.9
332	91.2	105.9	4.195	0.2384	56.228	302.70	884.7	1187.4
335	95.6	110.3	4.035	0.2478	56 120	305 80	882.3	1188.1
337	98.7	113.4	3.931	0.2542	56 048	307.90	880.7	1188.6
340	103.3	118.0	3.787	0.2641	55 940	311.00	878.3	1189.3
342	106.5	121.2	3.692	0.2709	55 866	313 00	876.7	1189.7
345	111.3	126.0	3.555	0.2813	55 755	316.20	874.2	1190.4
347	114.7	129.4	3.468	0.2884	55 681	318.30	872.6	1190.9
350	119.9	134.6	3.312	0.2992	55 570	321 40	870.1	1191.5
352	123.4	138.1	3.261	0.3067	55 492	323.50	868.5	1192.0
354	127.0	141.7	3.182	0.3143	55 414	325.60	866.8	1192.4
356	130.7	145.4	3.105	0.3221	55 336	327.70	865.2	1192.9
358	134.4	149.1	3.030	0.3301	55 258	329.80	863.5	1193.3
360	138.3	153.0	2.957	0.3382	55 180	331.90	861.8	1193.7
362	142.2	156.9	2.887	0.3464	55 100	334.00	860.2	1194.1
364	146.1	160.8	2.820	0.3546	55 020	336.10	858.5	1194.6
366	150.2	164.9	2.754	0.3631	54 940	338.20	856.8	1195.0
368	154.3	169.0	2.690	0.3717	54 860	340.30	855.1	1195.4
370	158.6	173.3	2.627	0.3806	54 780	342.40	853.4	1195.8
372	162.9	177.6	2.567	0.3896	54.696	344.50	851.7	1196.2
374	167.2	181.9	2.508	0.3998	54.612	346.60	850.0	1196.6
376	171.7	186.4	2.450	0.4081	54 528	348.70	848.3	1197.0
378	176.2	190.9	2.394	0.4177	54.444	350.80	846.5	1197.4
380	180.9	195.6	2.340	0.4270	54.360	352.90	844.8	1197.7
382	185.6	200.3	2.287	0.4370	54.276	355.00	843.1	1198.1
383	188.0	202.7	2.261	0.4420	54.234	356.10	842.2	1198.3
384	190.4	205.1	2.236	0.4470	54 192	357.20	841.3	1198.5
385	192.9	207.6	2.211	0.4520	54.15	358.20	840.5	1198.7
386	195.3	210.0	2 186	0.4570	54.108	359.30	839.6	1198.9
387	197.9	212.6	2.161	0.4630	54.066	360.30	838.7	1199.0
388	200.4	215.1	2.137	0.4680	54.024	361.40	837.8	1199.2
389	202.9	217.6	2.113	0.4730	53.982	362.40	837.0	1199.4
390	205.5	220.2	2.089	0.4790	53.940	363.50	836.1	1199.6
391	208.1	222.8	2.066	0.4840	53 896	364.60	835.2	1199.8
392	210.7	225.4	2.043	0.4890	53.852	365.60	834.3	1199.9
393	213.3	228.0	2.021	0.4950	53.808	366.70	833.4	1200.1
394	216.0	230.7	1.999	0.5000	53.764	367.70	832.5	1200.3
395	218.7	233.4	1.977	0.5060	53.720	368.80	831.6	1200.4
396	221.4	236.1	1.955	0.5120	53.676	369.90	830.7	1200.6
397	224.1	238.8	1.934	0.5170	53.632	370.90	829.9	1200.8
398	226.8	241.5	1.913	0.5230	53.588	372 00	829.0	1201.0
399	229.6	244.3	1.892	0 5290	53.544	373.00	828.1	1201.1
400	232.4	247.1	1.872	0 5340	53.500	374.10	827.2	1201.3
410	261.6	276.3	1.679	0 5960	53 000	384.70	818.2	1202.9
420	293.7	308.4	1.510	0.6620	52.600	395.40	809.0	1204.4
430	328.3	343.0	1.361	0.7350	52.200	406.20	799.6	1205.8
440	366.1	380.8	1.229	0 8140	51.700	417.00	790.1	1207 1
450	406.3	421.0	1.110	0.9000	51.200	428.00	780.0	1208.0

32 deg. F.—that is, the amount of heat in the liquid at 32 deg. F. is taken as the zero or starting point, from which the above quantities are calculated.

2b. Quality of Steam.—Steam in contact with the water, as in a boiler where it is generated, is known as saturated steam, and is termed wet saturated or dry saturated. The former contains a percentage of entrained water and this percentage determines the quality—that is, steam with a quality of 95% is steam having 5% of its weight in the form of water

2c. Superheated Steam.—If heat is added to dry saturated steam not in contact with the water and the pressure is maintained the same as when it was vaporized, it will then become superheated, or the temperature will be higher than that corresponding to the pressure at saturation. It will not become superheated in contact with the water. The specific heat of superheated steam changes with the pressure (0.48 average value). Superheat increases the specific volume of steam—that is, a greater number of cubic feet of superheated steam are produced at the same pressure from a given weight of water than of saturated steam. Therefore more mechanical work is available from a given expenditure of heat.

3. Air.—Pure air is a mixture of oxygen and nitrogen in proportion of 20.9% oxygen and 79.1% nitrogen by volume, and by weight, 23% oxygen and 77% nitrogen. Air in nature always contains other constituents in varying amounts, such as dust, carbon dioxide (CO_2), ozone, and water vapor. The physical and thermal properties of air are given in Table 3. This table is used in all heating problems which follow where the heat content of air is involved.

The specific heat of air, or the number of B.t.u. required to raise the temperature of 1 lb. of air 1 deg. F. is practically a constant and is taken as 0.24 B.t.u.

The CO_2 content of air in the open varies from 4 to 6 parts in 10,000 by volume, and the moisture varies from a very small amount to as high as 4% by weight. These ingredients spread out nearly uniformly in the atmosphere.

CO_2 is not poisonous but if present in large proportions, a person might die of suffocation. The amount present is regarded as an index of the quality of the air and indicates the character of the ventilation. It should not exceed 8 or 10 parts in 10,000 for good ventilation.

3a. Humidity.—Humidity is caused by water vapor (or moisture) being mixed with air in the atmosphere. The weight of water vapor a given space will contain is dependent entirely on the temperature—that is, the amount of vapor is exactly the same whether air is present or not. The air therefore simply affects the humidity by its temperature.

3b. Relative Humidity.—Relative humidity is the ratio of the weight of water vapor in a given space to the weight of this vapor which the same space will contain (full saturation) at the same temperature. Under normal conditions the external air has a relative humidity varying from 50 to 75% of full saturation. When the relative humidity is much above or below these limits, ill effects are experienced.

3c. Dew Point.—Dew point is the temperature at which saturation is obtained for a given weight of water vapor, or the temperature where any reduction in temperature would cause condensation of some of the water vapor in the form of dew particles.

HEATING

4. Transmission of Heat.—Heat is transmitted by conduction, convection, and radiation, and its intensity is measured by a thermometer. Temperature and pressure are no indication of work performed. They indicate merely a possible rate of performance.

Conduction is the transmission of heat from particle to particle of the same substance. This transmission will occur between portions of the same substance, the heat flowing in any direction from the higher to the lower temperature. Time is required for conduction to take place and varies with the distance, nature of the material, and temperature difference. The coefficient of conduction is the quantity of heat which flows in a unit of time through a cross section of unit area and a unit of thickness with a difference of 1 deg.

Convection is the transmission of heat by circulation of a fluid, or gas, over the surface of a colder or hotter body. The particles of the moving substances come in close contact with the hotter body and are actually heated by conduction during the period of contact and they then

TABLE 3.—PROPERTIES OF AIR OR WEIGHTS OF AIR, VAPOR OF WATER, AND SATURATED MIXTURES OF AIR AND VAPOR OF DIFFERENT TEMPERATURES, UNDER THE ORDINARY ATMOSPHERIC PRESSURE OF 29.921 IN. OF MERCURY

By R. C. Carpenter

Temperature Fahr.	Volume of dry air at different temperatures, the volume at 32° being 1.000	Weight of a cubic foot of dry air at different temperatures in pounds	Elastic force of vapor in inches of mercury (Regnault)	Mixtures of air saturated with vapor: Elastic force of the air in the mixture of air and vapor in inches of mercury	Mixtures of air saturated with vapor: Weight of a cubic foot of mixture: Weight of the air in pounds	Mixtures of air saturated with vapor: Weight of a cubic foot of mixture: Weight of the vapor in pounds	Mixtures of air saturated with vapor: Weight of a cubic foot of mixture: Total weight of mixture in pounds	Ratio of water to dry air	Ratio of dry air to water vapor	Cubic feet of vapor from one pound of water at pressure as in column 4	B.t.u. absorbed by 1 cu. ft. dry air per degree F.	B.t.u. absorbed by 1 cu. ft. saturated air per degree F.	Cubic feet dry air warmed 1 deg. per B.t.u.	Cubic feet saturated air warmed 1 deg. per B.t.u.
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0°	0.935	0.0864	0.044	29.877	0.0863	0.000079	0.086379	0.00092	1092.4	......	0.02056	0.02054	48.5	48.7
12	0.960	0.0842	0.074	29.849	0.0840	0.000130	0.084130	0.00115	646.1	......	0.02004	0.02006	50.1	50.0
22	0.980	0.0824	0.118	29.803	0.0821	0.000202	0.082302	0.00245	406.4	......	0.01961	0.01963	51.1	51.0
32	1.000	0.0807	0.181	29.740	0.0802	0.000304	0.080504	0.00379	263.81	3289.0	0.01921	0.01924	52.0	51.8
42	1.020	0.0791	0.267	29.654	0.0784	0.000440	0.078840	0.00561	178.18	2252.0	0.01882	0.01884	53.2	52.8
52	1.041	0.0776	0.388	29.533	0.0766	0.000627	0.077227	0.00819	122.17	1595.0	0.01847	0.01848	54.0	53.8
60	1.057	0.0764	0.522	29.399	0.0751	0.000830	0.075930	0.01083	92.27	1227.0	0.01818	0.01822	55.0	54.9
62	1.061	0.0761	0.556	29.365	0.0747	0.000881	0.075581	0.01179	84.79	1135.0	0.01811	0.01812	55.2	55.2
70	1.078	0.0750	0.754	29.182	0.0731	0.001153	0.074253	0.01548	64.59	882.0	0.01777	0.01794	56.3	55.5
72	1.082	0.0747	0.785	29.136	0.0727	0.001221	0.073921	0.01680	59.54	819.0	0.01770	0.01790	56.5	55.8
82	1.102	0.0733	1.092	28.829	0.0706	0.001667	0.072267	0.02361	42.35	600.0	0.01744	0.01770	57.2	56.5
92	1.122	0.0720	1.501	28.420	0.0684	0.002250	0.070717	0.03289	30.40	444.0	0.01710	0.01751	58.5	57.1
100	1.139	0.0710	1.929	27.992	0.0664	0.002848	0.069261	0.04495	23.66	356.0	0.01690	0.01735	59.1	57.8
102	1.143	0.0707	2.036	27.885	0.0659	0.002997	0.068897	0.04547	21.98	334.0	0.01682	0.01731	59.5	57.8
112	1.163	0.0694	2.731	27.190	0.0631	0.003946	0.067042	0.06253	15.99	253.0	0.01651	0.01711	60.6	58.5
122	1.184	0.0682	3.621	26.300	0.0599	0.005142	0.065046	0.08584	11.65	194.0	0.01623	0.01691	61.7	59.1
132	1.204	0.0671	4.752	25.169	0.0564	0.006639	0.063039	0.11771	8.49	151.0	0.01596	0.01670	62.5	59.9
142	1.224	0.0660	6.165	23.756	0.0524	0.008473	0.060873	0.16170	6.18	118.0	0.01571	0.01652	63.7	60.6
152	1.245	0.0649	7.930	21.991	0.0477	0.010716	0.058416	0.22465	4.45	93.3	0.01544	0.01654	64.8	60.5
162	1.265	0.0638	10.099	19.822	0.0423	0.013415	0.055715	0.31713	3.15	74.5	0.01518	0.01656	65.9	60.4
172	1.285	0.0628	12.758	17.163	0.0360	0.016682	0.052682	0.46338	2.16	59.2	0.01494	0.01658	67.1	60.3
182	1.306	0.0618	15.960	13.961	0.0288	0.020536	0.049336	0.71300	1.402	48.6	0.01471	0.01687	68.0	59.3
192	1.326	0.0609	19.828	10.093	0.0205	0.025142	0.045642	1.22643	0.815	39.8	0.01449	....	68.9	
202	1.347	0.0600	24.450	5.471	0.0109	0.030545	0.041445	2.80230	0.357	32.7	0.01426	....	70.2	
212	1.367	0.0591	29.921	0.000	0.0000	0.036820	0.036820	Infinite	0.000	27.1	0.01406	....	71.4	

pass on, carrying the heat absorbed and making way for fresh cooler particles. This circulation may be caused by natural forces or may be produced mechanically. The circulation of water in a boiler is an example of the former, while air passing over heater coils in a fan blast heating system is an example of the latter condition. In case the circulating medium is hotter than the other body, the process of heat transfer will be reversed. In general, it may be said that the heat transferred by convection is independent of the nature of the substance and of the surrounding absolute temperature. The heat transferred depends (1) on the velocity of the medium—varying as some function of this velocity, (2) on the form and dimensions of the body, and (3) on the temperature difference.

Radiation is the transmission of heat through a medium, commonly known as the ether, which is assumed to occupy all intermolecular spaces. Radiation takes place under the same law as light—in straight lines—and its intensity varies inversely as the square of the distance through which the heat is transmitted. Radiant heat continues to travel in a straight line until intercepted or absorbed by some body. The amount of radiant heat emitted or absorbed depends largely upon the character of the surface of the hot or cold body, and it has been found that the power of absorption of a substance is exactly the same as the power of emission of heat.

RELATIVE RADIATING OR ABSORBING POWER AT 212 DEG.

	Effects of kind of material (Based on lamp black as 100 %)		Effects of painting (Based on bare iron as 100 %)
Lamp black	100	Bare iron	100
White lead	100	Aluminum or copper bronze	75
Paper	98	Snow white enamel	101
Glass	90	White lead paint	99
Steel	17	White zinc paint	101
Platinum	17		
Copper	7		

Radiant heat has the property of passing through dry gases without heating them to any appreciable extent, but air containing water vapor or dust will intercept and absorb radiant heat.

5. Transmission of Heat through Building Materials.[1]—The quantities of heat transmitted through building materials are known as heat losses and should be carefully estimated. The following methods of computation will indicate how they may be reduced by proper construction, thereby decreasing the fuel required for heating in winter.

The amount of heat that must be supplied in order to warm a room may be divided into: (*a*) the heat required to offset the heat transmission of walls, ceiling, roof, and floor; and (*b*) heat required to warm the air entering the room from the outside by infiltration or otherwise, commonly known as the air change. Heat supplied by persons, lights, machinery, and motors may be deducted from the sum of items (*a*) and (*b*).

TABLE 4.—USUAL INSIDE TEMPERATURES, DEGREES FAHRENHEIT

Public buildings	68 to 72	Bath rooms	85
Factories	65	Schools	70
Machine shops	60 to 65	Hospitals	72 to 75
Foundries, boiler shops	50 to 60	Paint shops	80
Residences	70		

[1] Experimental data in this article taken from the Univ. of Illinois Bull. 102, entitled "A Study of the Heat Transmission of Building Materials," by A. C. Williard and L. C. Lichty.

Table 5.—Climatic Conditions in the U. S. Wind Velocities and Temperatures

State	City	Temperature Deg. F.		Wind velocity	
		Lowest	Average	Maximum	Average
Alabama	Mobile	−1	57.7	..	..
	Montgomery	−5	56.1	54	5
Arizona	Flagstaff	−21	34.8	..	..
	Phoenix	12	58.9	..	..
Arkansas	Fort Smith	−15	49.5	66	5
	Little Rock	−12	52.0	..	..
California	San Francisco	29	....	60	9
	Independence	10	48.7	..	..
	San Diego	32	57.2	43	6
Colorado	Denver	−29	38.4	75	7
	Grand Junction	−16	39.2	..	..
Connecticut	Southington	−19	36.3	..	..
	Hartford	−14	....	..	..
	New Haven	−14	....	..	..
District of Columbia	Washington	−15	42.9	66	5
Florida	Jacksonville	10	60.9	70	6
	Pensacola	7	56.0	..	..
Georgia	Savannah	8	57.2	88	7
	Atlanta	−8	51.4	66	9
Idaho	Boise	−28	39.6	55	4
	Lewiston	−18	42.5	..	..
Illinois	Chicago	−23	35.9	84	9
	Springfield	−22	39.0	..	..
Indiana	Indianapolis	−25	40.4	..	..
	Evansville	−15	44.0	..	..
Iowa	Sioux City	−31	32.1	..	..
	Keokuk	−26	37.6	60	8
	Dubuque	−32	32.0	60	5
Kansas	Wichita	−22	42.9	..	..
	Dodge City	−26	36.0	75	11
Kentucky	Louisville	−20	45.0	60	7
Louisiana	New Orleans	7	60.5	66	7
	Shreveport	−5	55.7	..	..
Maine	Portland	−17	33.5	61	5
	East Port	−21	31.1	78	9
Maryland	Baltimore	−7	43.3	..	..
Massachusetts	Boston	....	....	72	11
Michigan	Detroit	−24	35.3	76	9
	Alpena	−27	29.1	72	9
Minnesota	Duluth	−41	25.5	78	7
	Minneapolis	−33	28.4	..	..
Mississippi	Vicksburgh	−1	56.0	62	6
Missouri	Springfield	−29	43.0	..	..
	St. Louis	−22	39.0	80	11
Montana	Helena	−42	30.9	70	6
	Havre	−55	27.7	76	11
Nebraska	Lincoln	−29	35.8	..	..
	North Platte	−35	34.6	96	9
Nevada	Carson City	−22	34.8	..	..
New Hampshire	Concord	−35	33.1	..	..
New Jersey	Atlantic City	−7	41.6	..	..
New York	New York City	−6	40.1	96	9
	Saranac Lake	−38	34.1	..	..
New Mexico	Santa Fe	−13	38.0	53	6
N. Carolina	Charlotte	−5	49.8	55	5
N. Dakota	Bismark	−44	23.5	74	8

TABLE 5.—CLIMATIC CONDITIONS IN THE U. S. WIND VELOCITIES AND TEMPERATURES
Continued

State	City	Temperature Deg. F.		Wind velocity	
		Lowest	Average	Maximum	Average
Ohio	Toledo	−16	36.8	72	9
	Columbus	−20	39.8	.	..
	Cincinnati	−17	39.0	59	7
Oklahoma	Oklahoma	−17	47.1	.	..
Oregon	Baker City	−20	34.1	..	..
	Portland	−2	45.1	..	..
Pennsylvania	Pittsburgh	−20	40.8	69	6
	Philadelphia	−6	41.8	75	10
Rhode Island	Providence	−9	37.5	..	..
S. Carolina	Charleston	7	56.9	..	..
	Columbia	2	53.5	..	..
S. Dakota	Huron	−13	25.9	69	10
	Yankton	−32	31.2	.	..
Tennessee	Knoxville	−16	47.0	84	5
	Memphis	−9	50.7	75	6
	Chattanooga	−10	48.0	60	6
Texas	Forth Worth	−8	49.5	..	..
	Galveston	8	56.0	84	10
Utah	Salt Lake City	−20	39.7	66	5
Vermont	North Field	−32	27.8	..	..
	Burlington	−25	32.0	..	..
Virginia	Lynchburg	−5	45.2	53	4
	Norfolk	2	45.0	..	..
Washington	Seattle	3	44.3	.	..
	Spokane	−30	37.0	52	4
W. Virginia	Parkersburg	−27	41.9	..	..
	Elkins	−21	38.8	..	..
Wisconsin	Milwaukee	−25	32.4	..	..
	La Crosse	−43	31.2	..	..
Wyoming	Cheyenne	−38	33.7	..	..
	Lander	−36	29.0	..	..

In computing the heat losses and boiler power, the first consideration is the temperature range between the inside and outside of building. Table 4 gives the customary required inside temperature of various classes of buildings. Table 5 gives the lowest and average temperatures, and the maximum and average wind velocities for different localities. Minimum temperatures are misleading as they seldom occur, and then for only short periods. The best way to determine the minimum temperature on which to calculate the heat losses is to compare the average temperature of the locality under consideration with the one in which you reside and are familiar. In New York the minimum temperature (Table 5) is −6 deg. F. and in Detroit, −24 deg. F., while the averages are 40.1 deg. F. and 35.3 deg. F., yet all contracts are let on the basis of sufficient radiation for the room temperature in 0 deg. F. weather, in both places.

If radiation is provided for the minimum outside temperature, it will be at an unnecessary expense. Boiler, chimney, and grate should be of sufficient size to take care of the lowest temperature periods by raising the temperature of the radiation, or pressure of the heating medium.

The combined coefficient, U, may be defined as the amount of heat absorbed or given off per square foot of surface per hour, by radiation and convection under certain conditions of air movement, for each degree difference in temperature between the surface and the average temperature of the air. If the air movement is different on the two sides of a wall, the value of the combined coefficient will of course, be different owing to the fact that the heat loss by convection is different. Let K_1 = the combined coefficient for the inside wall; K_2 = the combined coefficient for the outside wall; $K_1(t - t_1)$ = the heat absorbed by the inside wall per sq. ft. per hr.; and $K_2(t_2 - t_0)$ = the heat given off by the outside wall surface per sq. ft. per hr. Then

$$K_1(t - t_1) = K_2(t_2 - t_0)$$

in which t and t_1 = temperature of the inside air and inside wall surface respectively, and t_0 and t_2 = temperature of the outside air and outside wall surface respectively.

The average value of K_1 is 1.31 and K_2 increases with the velocity of wind over the surface. K_2 is taken generally at 3 times that of the inside wall surface. Following are the multipliers of K_2 for various wind velocities.

Wind velocity (miles	Brick	Wood
5	2.38	2.19
10	3.20	2.71
15	3.76	2.95
20	4.22	3 02

The amount of heat that will be transmitted through a material having parallel surfaces due to a difference in temperature between those surfaces is termed the conductivity of the material. The amount of heat that a given material will transmit is directly proportional to the difference in temperature between the surfaces and inversely proportional to the thickness. Let C = coefficient of conductivity or B.t.u. transmitted per square foot per hour per inch of thickness per 1-deg. F. difference in temperature of the two surfaces; t_1 = temperature of the inside wall surface; t_2 = temperature of the outside wall surface; and X = thickness of the wall in inches. Then

$\frac{C}{X}(t_1 - t_2)$ = heat transmitted by conduction per sq. ft. per hr.

TABLE 6.—COEFFICIENTS TO BE USED IN DETERMINING "U" FOR DIFFERENT MATERIALS

Material	"C" per 1 in. thick per sq. ft. per deg.	K in still air per degree	Factor to be used for K_2	K_2 Wind velocity 15 to 20 miles per hour
Dry brick wall	4 0	1 4	3	4 2
Brick wall with moisture	5 0	1 4	3	4 2
Sandstone	9 0	1.3	4	5 2
Concrete, 1-2-4 mix	8 3	1 3	4	5 2
Plaster or mortar	8 0	0 93	3	2 97
Wood (fir), one surface finished	1.0	1 4	3	4 2
Cork board	0 32	1 25	3	3 75
Magnesia board	0 50	1 45	3	4.35
Asbestos board	0.50	1 6	3	4 8
Sheet asbestos	0 3	1 4	3	4.2
Packed mineral wool	0.35	1 4	3	4.2
Glass—single (91.4 %, total area)	2 06	1 5	3	4 5
Glass—double (½-in. air space, 69.3 % area)	1 5	1 5	3	4 5
Roofing—2-in. tile*	5 3	1 25	3	3 75
2-in. tile roofing, plastered*	0 84	1 25	3	1 75
2-in. tile, ½-in. plaster, both sides*	1 00	0 93	3	2 79
4-in. tile, ½-in. plaster, both sides*	0 60	0 93	3	2.79
6-in. tile, ½-in. plaster, both sides*	0 47	0.93	3	2 79

* For thickness stated, not for 1 in.

Building Insulation.—The insulation of walls and roofs of buildings is becoming a general practice. Mineral wool may be used packed between the joists. Sheet corkboard about 1 in. thick makes excellent insulation. Flaxlinum and Celotex board are a form of fibrous material which is applied in sheets.

Insolex is a form of gypsum with many minute air holes. This is poured wet between rafters and studs, making a porous wall 4 in. thick.

There have been many claims that radiation may be reduced one-half by the use of these materials. This is not true, as the only change in the computation of the heat losses would be in the wall and roof; the glass and infiltration will probably remain as before. From Table 13 it is readily seen that the roof losses occur only on the top floor and the wall loss entire is less than one-third the heat loss, and if this were cut in half the radiation would be reduced by only about one-sixth. From the discussion of heat-loss factors and Table 6, it will be seen that the surface factor K is nearly as great as 1 in. in thickness of several materials.

By reducing several smooth surfaces enclosing air spaces, the thickness and quality of the insulating material is immaterial. Several ⅜-in. wood boards with ¼-in air spaces would probably serve as well as 1 in. of special material. It is an excellent practice, but multiple air spaces will give better results than an extremely thin single layer of very efficient material.

6. Calculation of Heat Transmission through Walls, Roofs, and Floors.[1]—The amount of heat received by the inside wall surface, the amount conducted through the wall, and the amount emitted must all be equal. Let U = the heat transmission of the actual wall per square foot per hour per degree difference in temperature on the two sides. Then

$$U(t - t_0) = K_1(t - t_1) = \frac{C}{X}(t_1 - t_2) = K_2(t_2 - t_0)$$

Since

$$(t - t_0 = (t - t_1) + (t_1 - t_2) + (t_2 - t_0)$$

$$U = \frac{1}{\frac{1}{K_1} + \frac{1}{K_2} + \frac{X}{C}}$$

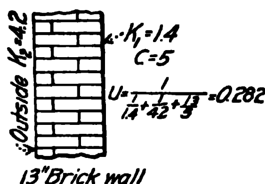


Fig. 1.

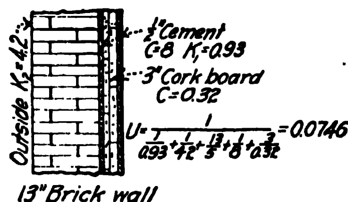


Fig. 2.

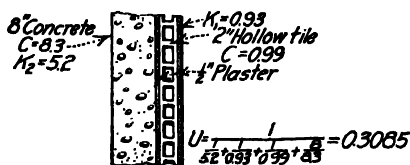


Fig. 3.

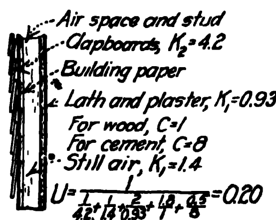


Fig. 4.

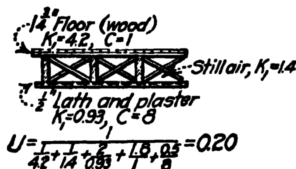


Fig. 5.

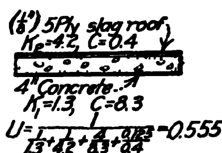


Fig. 6.

The value of $\frac{X}{C}$ for paper and very thin substances may be neglected. If the wall is composed of several layers of different materials in contact with an air space of thicknesses X_1, X_2, X_3, etc., then

$$U = \frac{1}{\frac{1}{K_1} + \frac{1}{K_2} + \frac{X_1}{C_1} + \frac{X_2}{C_2} + \frac{X_3}{C_3} \text{ etc.}}$$

K_1, K_2, and C being taken from Table 6 for the particular materials involved. Figs. 1, 2, 3, 4, 5, and 6 illustrate the methods of computing U for various types of walls, floors, and roofs.

It is customary for engineers to increase heat losses by a factor, called the *exposure factor*. Such an increase, however, is unnecessary if the above method is followed and the proper values used. The values in Table 7 have been calculated in accordance with the method above advocated, using results of the Illinois tests. If the values given are used with judgment, good results will be obtained. A typical heat loss schedule is given in Table 13, p. 1162.

[1] Method described is taken from the Univ. of Ill. *Bull.* 102, entitled "A Study of the Heat Transmission of Building Materials," by A. C. Willard and L. C. Lichty.

Table 7.—B.t.u. Losses of Building Materials

$$U = \frac{1}{\frac{1}{K_1} + \frac{1}{K_2} + \frac{X_1}{C_1} \text{ etc.}} \qquad X = \text{thickness in inches}$$

Material and thickness		U	40	45	50	55	60	65	70	75	80	85	90	95	C_1	K_1	K_2
			Outside temperature difference												Experiment factors		
Brick wall	4 in.	0.57	23.0	25.6	28.5	31.3	34.2	37.0	39.9	42.7	45.6	48.5	51.3	54.1	5.0	1.4	4.2
	8 in.	0.40	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0			
	12 in.	0.30	12.0	13.5	15.0	16.5	18.0	19.5	21.0	22.5	24.0	25.5	27.0	28.5			
	16 in.	0.241	9.6	10.8	12.0	13.3	14.5	15.7	17.0	18.1	19.3	20.5	21.7	22.9			
	18 in.	0.22	8.8	9.9	11.0	12.1	13.2	14.3	15.4	16.5	17.6	18.7	19.8	20.9			
	20 in.	0.202	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.2	16.2	17.2	18.2	19.2			
	24 in.	0.174	7.0	7.8	8.7	9.6	10.4	11.3	12.2	13.0	13.9	14.8	15.7	16.5			
Stone wall	8 in.	0.54	21.6	24.3	27.0	29.7	32.4	35.1	37.8	40.5	43.2	45.9	48.6	51.3	9.0	1.3	5.2
	12 in.	0.436	17.4	19.6	21.8	24.0	26.2	28.3	30.5	32.7	34.9	37.1	39.2	41.4			
	16 in.	0.365	14.6	16.4	18.25	20.1	21.9	23.7	25.6	27.4	29.2	31.0	32.8	34.7			
	20 in.	0.314	12.6	14.1	15.7	17.3	18.6	20.4	22.0	23.6	25.1	26.7	28.3	29.8			
	24 in.	0.276	11.0	12.4	13.8	15.2	16.6	17.9	19.3	20.7	22.1	23.5	24.8	26.2			
Concrete slab or wall	2 in.	0.833	33.3	37.5	41.6	45.8	50.0	54.1	58.3	62.4	66.6	70.8	75.0	79.1	8.3	1.3	5.2
	4 in.	0.693	27.7	31.2	34.7	38.1	41.6	45.0	48.5	52.0	55.4	58.9	62.4	65.8			
	6 in.	0.594	23.8	26.7	29.7	32.7	35.6	38.6	41.6	44.6	47.5	50.5	53.5	56.4			
	8 in.	0.52	20.8	23.4	26.0	28.6	31.2	33.8	36.4	39.0	41.6	44.2	46.8	49.4			
	10 in.	0.46	18.4	20.7	23.0	25.3	27.6	29.9	32.2	34.5	36.8	39.1	41.4	43.7			
	12 in.	0.415	16.6	18.7	20.8	22.8	24.9	27.0	29.0	31.1	33.2	35.3	37.4	39.4			
	16 in.	0.346	13.8	15.6	17.3	19.0	20.8	22.5	24.2	26.0	27.7	29.4	31.1	32.9			
	20 in.	0.296	11.8	13.3	14.8	16.3	17.8	19.2	20.7	22.2	23.7	25.2	26.6	28.1			
	24 in.	0.26	10.4	11.7	13.0	14.3	15.6	16.9	18.2	19.5	20.8	22.1	23.4	24.7			
Hollow tile	2 in.	0.409	16.4	18.4	20.5	22.5	24.5	26.6	28.6	30.7	32.7	34.8	36.8	38.7	0.99	0.93	2.79
	4 in.	0.325	13.0	14.6	16.3	17.9	19.5	21.1	22.8	24.4	26.0	27.6	29.3	30.9	0.61		
	6 in.	0.281	11.2	12.6	14.0	15.5	16.9	18.3	19.7	21.1	22.5	23.9	25.3	26.7	0.47		
Lath, plaster and stud															1.0	0.93	
Clapboards and sheathing		0.2	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	8.0	1.4	4.2
Solid wood	7/8 in.	0.547	21.9	24.6	27.4	30.1	32.8	35.6	38.3	41.0	43.8	46.5	49.2	52.0	1.0	1.4	4.2
	1 3/4 in.	0.37	14.8	16.6	18.5	20.4	22.2	24.0	25.9	27.8	29.6	31.5	33.3	35.2	.....	1.4	4.2
	2 5/8 in.	0.279	11.2	12.6	14.0	15.4	16.7	18.1	19.5	20.9	22.3	23.7	25.1	26.5	.....	1.4	4.2
5 ply slag roof	2-in. plank	0.306	12.2	13.7	15.3	16.8	18.4	19.9	21.4	22.9	24.5	26.0	27.5	29.1	1.0	1.4	4.2
	3-in. plank	0.235	9.4	10.6	11.75	12.4	14.1	15.3	16.4	17.6	18.8	19.9	21.1	22.3	0.4	1.4	4.2
	2-in. concrete	0.64	25.6	28.8	32.0	35.2	38.4	41.6	44.8	48.0	51.2	54.4	57.6	60.8	8.3		
	3-in. concrete	0.60	24.0	27.0	30.0	33.0	36.0	39.0	42.0	45.0	48.0	51.0	54.0	57.0	0.4	1.3	4.2
Glass—single		1.125	45.0	50.6	56.3	61.9	67.5	73.1	78.3	84.3	90.0	95.6	101.3	106.9	.....	1.5	4.5
Glass—double		0.45	18.0	20.3	22.5	24.7	27.0	29.3	31.5	33.8	36.0	38.3	40.5	42.5			
Corrugated iron No. 14 (unlined 0.08)		1.11	4.4	50.0	55.5	61.0	66.6	72.2	77.7	83.3	88.8	94.4	99.9	105.5	10.0	1.5	4.5
B.t.u. per cu. ft. × 0.075 × ($t - t_1$) × 0.24 = 0.018						0.99	1.08	1.17	1.26	1.35	1.44	1.53	1.62	1.71			
Air infiltration. Values below for 1/16-in. crack—1/2 of these values for 1/32-in. crack																	
(P = perimeter of window in feet) 60 × 13 × 0.147 × 0.086 × 0.24 = 2.4 P per degree per ft.		2.4	96.0	108.0	120.0	132.0	144.0	156.0	168.0	180.0	192.0	204.0	216.0	228.0			

It has been recommended that the temperature difference usually considered under roofs be increased. This should be done with judgment since, as a rule, the top floor, with the roof loss properly figured, will have too much radiation.

The first floor where doors occur usually has too little radiation. This is especially true when the doors are opened often. The elevator shaft and doors aggravate this condition as the hot air rises to the top floor.

The following temperature differences may be taken for attic rooms and cellars:

Closed attic—metal or slate roofs	14 deg. F.
Closed attic—cement tile roofs	23 deg. F.
Cellars kept closed	32 deg. F.

Thus, the heat loss per hour estimated for a room having a floor $1\frac{1}{2}$-in thick over a cellar, assuming room heated to 70 deg. F., may be calculated as follows:

$$K = 1.4 \text{ both sides} \qquad C = 1$$

$$U = \frac{1}{\frac{1}{1.4} + \frac{1}{1.4} + \frac{1.5}{1}} = 0.3413 \text{ B.t.u. per hr. per sq. ft. per deg.}$$

Heat loss per hour = (0.3413)(70 − 32) = 13.0 B.t.u. per sq. ft. Heat loss from floors that are laid directly on the ground may be estimated on the assumption that the ground temperature is 50 deg. F. The loss per hour through 4 in. of concrete for an inside temperature of 65 deg. F. is

$$U = \frac{1}{\frac{1}{1.3} + \frac{4}{8}} = 0.8 \text{ B.t.u. per sq. ft. per deg.}$$

Heat loss per hour = (0.8)(65 − 50) = 12 B.t.u. per sq. ft.

7. Heat Loss by Infiltration.—Heat loss by infiltration is estimated in many cases by the number of air changes arbitrarily assumed. It is also estimated by measuring the periphery of the window casing, assuming a $\frac{1}{32}$ or $\frac{1}{16}$-in. crack, with the wind blowing at a certain velocity. This is largely dependent on the character and grade of the building construction. The results of these determinations are, at best, inaccurate and there is no reason for going into refinements of calculation beyond the limit of error of the assumptions.

Three methods are given for determining the infiltration loss: (1) Assume arbitrarily a number of complete air changes of cubic contents of the buildings or rooms; (2) assume a $\frac{1}{16}$ or $\frac{1}{32}$-in. crack all around the windows with a given wind velocity to determine the air change; and (3) assume the proper crack or opening $\frac{1}{16}$ in. and determine the relation of this infiltration in the form of a ratio of square feet of glass to cubic contents.

Table 8.—Results of Experiments on Air Infiltration

Velocity of outside air (miles per hr.)	Cubic feet per minute leakage through 14 ft. of crack, $\frac{1}{16}$-in. clearance		Cubic feet per minute per foot of $\frac{1}{16}$-in. crack per mile velocity
	Weather stripped	Ordinary sash	
6.0	1.0	12.0	0.143
9.1	1.6	19.0	0.148
9.5	1.65	20.0	0.147
9.6	1.75	19.6	0.148

For a wind velocity of 10 miles per hour, $\frac{1}{16}$-in crack will deliver about 90 cu. ft. per running foot of crack per hour (0.148 × 10 × 60 = 88.8), as shown in Table 8.

In Table 7 the air infiltration is calculated, assuming 0.147 cu. ft. per minute per running foot of $\frac{1}{16}$-in. crack per mile velocity, the air velocity at 13 miles per hour, the air at 0 deg. F., or 0.086 lb. per cu. ft. (see Table 3), and specific heat at 0.24 B.t.u. (see Art. 3). The B.t.u. per hour per degree difference per running foot of crack = 60 min. × 13 mi. per hr. × 0.147 cu. ft. per min. per ft. per mile × 0.086 × 0.24 = 2.4 B.t.u. per deg. per ft., or 1.2 B.t.u. per deg. per ft. for $\frac{1}{32}$-in. crack. Windows on only two sides of room should be figured as the draft will be outward on the leeward side.

Table 9.—Table of Assumed Air Changes

Halls	3 per hr.
Rooms of 1st floor	2 per hr.
Offices—stores	2 per hr.
Offices—2nd floor	1 per hr.
Factories—large areas	¾ per hr.
Garages	2 per hr.

TABLE 10.—RELATION OF AIR CHANGES TO CUBIC CONTENTS

Percentage of glass (sq. ft.) to cubic contents (cu. ft.)	2	2½	3½	4½	6	7	8	9
Air change per hour	⅜	½	¾	1	1¼	1½	1¾	2

Double the above amounts for rooms having doors to outside opened frequently, as on ground floors. Note the comparison by the above two methods in Tables 13 and 13A.

8. Heat Supplied by Persons, Lights, and Machinery.—The following allowances may be made for persons and lights when required, but as buildings have to be heated at times when these sources of heat may be absent, as Sundays, they should be made with care. It would probably be safer to omit them when figuring the radiation, as is generally done, and shut off some of the heating surface when these sources of heat are present. The heat given off by persons is not considered except in assembly halls. These halls are generally figured for 50 deg. F. in 0-deg. weather when the audience is not present.

TABLE 11

Man at rest	400 B.t.u. per hr.
Man at work	500 B.t.u. per hr.

Electric lamps: B.t.u. per hr. = watts per lamp × number × 3.415

Motors and machinery convert some of their energy into heat if located in the same room. Rubber and chocolate rolls and similar classes of machinery produce great quantities of heat.

9. Measurement of Flow of Fluids. There are three fluids used in heating, for which pipe sizes have to be determined, viz., steam, water, and air. The power required for circulation and loss in head due to friction has to be known in determining the proper sizes of conduits. All fluids flowing in conduits obey the same laws and with corrections for density, the variables in the formulas are the same.

The potential head, or measured head, is the vertical distance measured from some base line to the center of the pipe at the point under consideration. In the measurement of the flow of gases, as air or steam, the pressure at the point of flow has to be taken into account in determining the density.

The general formula for all fluids flowing in pipes is

$$h = f \cdot \frac{lR}{A} \cdot \frac{V^2}{2g}$$

in which h = loss of head in friction; f = coefficient of friction, 6.02 of water (average) but it actually varies with the diameter of pipe and velocity; l = length in feet; R = hydraulic radius, or the perimeter divided by the area; $2g$ = 64.34; and V = velocity in feet per second

For round pipes the formula reduces to

$$h = f \cdot \frac{l}{d} \cdot \frac{V^2}{2g}$$

The above formulas have been superseded by exponential formulas determined by plotting the values on logarithmic paper and determining the angle of inclination of the straight lines.

Diagram 1, by H. V. Carpenter, was published in *Power*, December 17, 1912. It gives steam discharge in pounds per minute, size of pipe, and drop in pressure per 100 ft., for sizes of pipe from 1 to 20 in. and is plotted from Unwin's or Babcock's formula, and verified by tests by R. C. Carpenter.

$$V = 16{,}050\sqrt{\frac{Pd}{Ly\left(1 + \frac{3.6}{d}\right)}}$$

$$W = 87.5\sqrt{\frac{Pyd^5}{L\left(1 + \frac{3.6}{d}\right)}}$$

in which V = velocity of the steam in feet per minute; P = drop in pressure in length L; d = diameter of pipe in inches; y = density of the steam in pounds per cubic foot; and W = weight of steam delivered in pounds per minute.

This chart is for high pressure steam. For a 3-in. pipe, the discharge is seen to be 33 lb. per min., with 210 lb. average absolute pressure and 0.30 lb. drop per 100 ft. of pipe. For any lower pressure as 80 lb., follow between the inclined lines as shown, obtaining a discharge of 21 lb. per min.

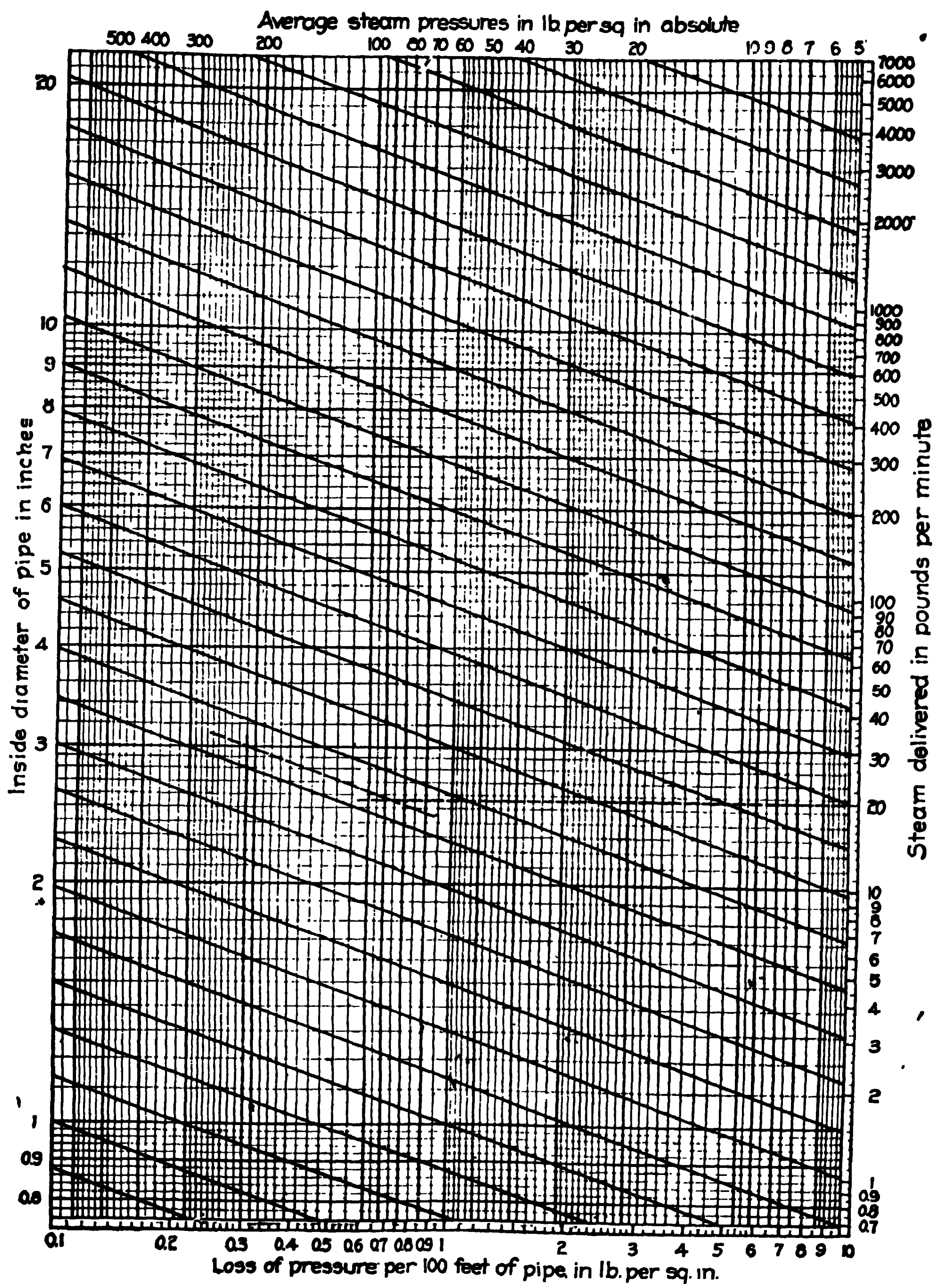


DIAGRAM 1.—Pipe capacities and pressure drop. High pressure steam.

10. Radiation.

10a. Heat Transmission for Radiation.—Various tests have been made to determine the rate of transmission for radiation under varying conditions of temperature. The best data are those deduced by J. R. Allen when director of the laboratory of the A. S. H. and V. E. at Pittsburgh. Diagrams 1*A* and 1*B* are applicable to the new types of tube radiation of any manufacturer by simply substituting the square feet per section in that particular manufacturer's catalogue. The square feet per section on the chart is an average assumption in order to make the unit of measure per section in the same terms as for the old column radiation.

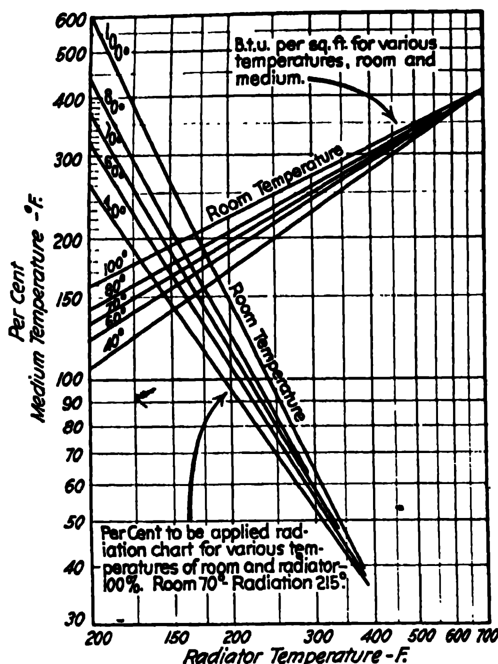


Diagram 1*A*.

The deduction takes account of the height, length, and width, and Diagram 1*B* is compiled for a room temperature of 70 and 215 deg. as the temperature of the medium.

Diagram 1*A* and Table 12 give the percentages required for other temperature conditions of the room and medium.

The symbols in the formula are as follows:

Q = total B.t.u. given off by the radiator per square foot per hour of uncoated rated surface

R = rates of the enveloping surface to actual surface

T_S = absolute temperature of the steam or water in the radiator in degrees Fahrenheit in this case (459.6 + 215) = 674.6 deg.

T_R = temperature of the air of the room in this case (459.6 + 70) = 529.6 deg. F.

t_s = temperature of the steam or water in the radiator in this case 215 deg. F.

t_r = temperature of the room 70 deg. F.

0.157 = a constant for cast-iron radiation

K_c = a constant for the radiator which, multiplied by the expression ($t_s - t_r$), gives the heat loss by convection per square foot of rated surface per hour

$$Q = 0.157R\left[\left(\frac{T_S}{100}\right)^4 - \left(\frac{T_R}{100}\right)^4\right] + K_c(t_s - t_r)$$

Substituting values, for charts,

$$Q = 0.157R[(6.746)^4 - (5.296)^4] + K_c(215 \text{ deg.} - 70 \text{ deg.})$$
$$Q = 201R + (K_c \times 145)$$

Values for K_c

Height of radiator, inches..	45	38	36	34	32	26	23 and below
K_c..........	1.008	1.028	1.042	1.056	1.069	1.089	1.096
B.t.u. (K_c × 145).........	146	149	151	153	155	158	159

Values of *R* have been computed for all radiators, the convection factor added, and curves plotted. They prove to be straight lines in all cases. The effect of the manu-

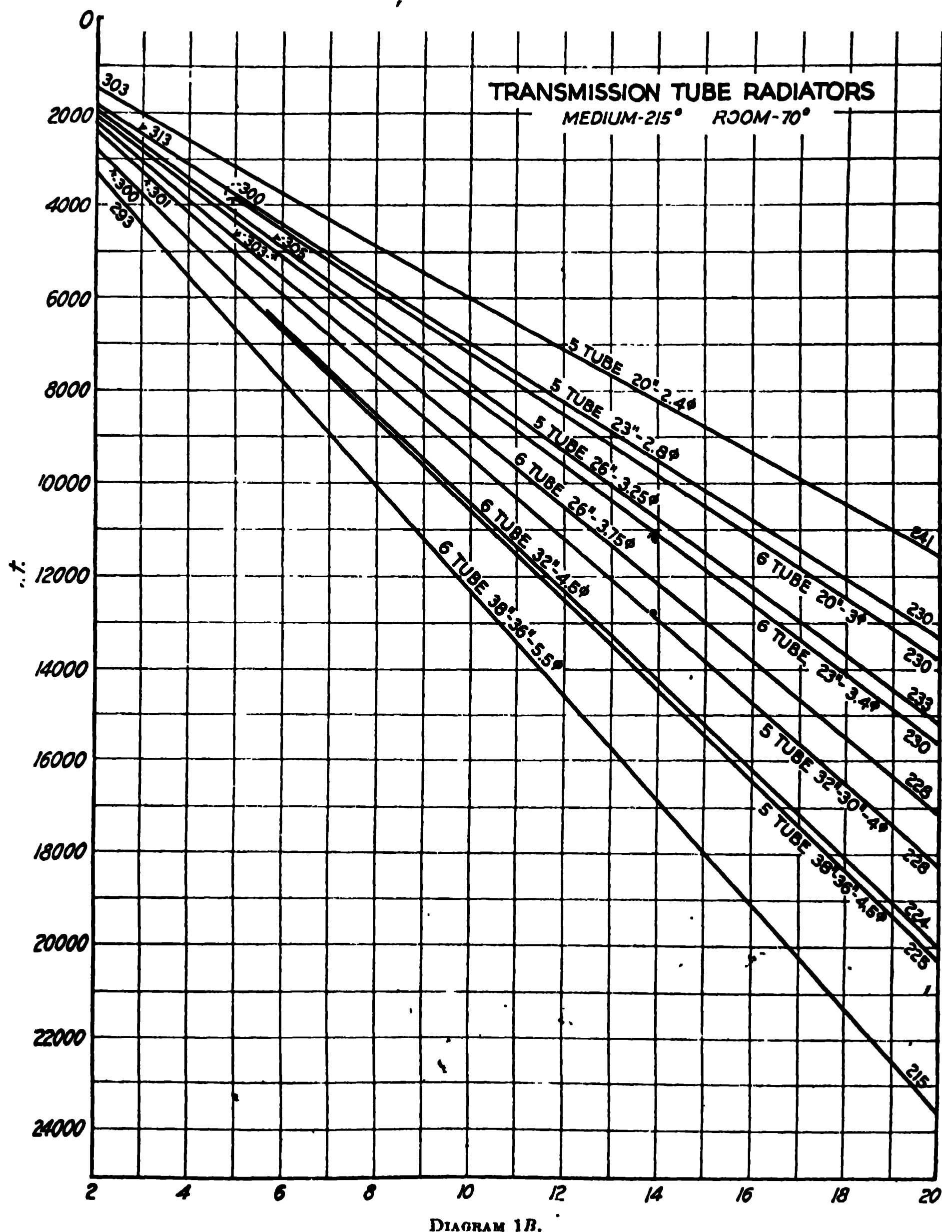


Diagram 1*B*.

facturer's rating in square feet is practically eliminated as far as influencing the transmission is concerned.

The square feet marked on the lines may be neglected for that section in the catalogue of the particular manufacturer under consideration.

In arriving at the quantity marked in Diagram 1B, the average square feet per section was used; therefore, the curves are universal for any manufacturer.

TRANSMISSION TUBE RADIATORS

MEDIUM-215°, ROOM-70°

B.t.u.

Number of Sections

Diagram 1B.—(*Continued.*)

The B.t.u. notation at the end of the curves indicates the maximum and minimum transmission per square foot of the number of sections included. Diagram 1A is a logarithm curve giving the ratio of various room- and medium-temperature differences to that of 215 and 70 deg. on which the diagram is based. Table 12 is the same thing in analytical form.

Example.—The heat loss of a room in Table 13 is 31,144 B.t.u. Using Diagram 1*B* for 32-in., six-tube radiators, we have one 20 section and one 11 section. These give 20,000 and 11,400 B.t.u. or 31,400 B.t.u. and at 4.5 sq. ft. per section, one 90-sq. ft. radiator and one 49.5-sq. ft. or 139.5 sq. ft. total. In case the temperatures were 170 and 70 deg. F., instead of 215 and 70 deg., we should have, by Table 12 and Diagram 1*A*, 153% of the above, or 214 sq. ft., or 48 sections with 4.5 sq. ft. per section. If the particular catalogue lists this radiator as 5 sq. ft. per section, simply list the radiator as 240 and 155 sq. ft. Let the number of tubes and sections be the determining factor, and neglect the square feet except as necessary to define the radiator. It will be found that manufacturers are listing their radiators at various ratings, although there is little or no difference in the capacities. Of course, the company that lists its sections at the least rating will probably have the lowest price. By means of these diagrams it is very easy to determine the most economical radiator based on its capacity.

The standard for rating direct radiation, as used in manufacturers' catalogues, is 70 deg. F. room temperature and 215 deg. F. inside the radiator, or 150 deg. F. difference between the room and the heating medium for steam. From Table 12, for a two-column, 38-in. radiator, $U' = 236$ B.t.u., which, divided by 970 B.t.u. (the latent heat at atmospheric pressure), gives 0.24 lb. of steam condensed per sq. ft. per hr. Hot-water boilers and radiators are rated for an average temperature of water of 170 and 70 deg. F. in the room, or 150 B.t.u.

It will be seen that very few of the radiators, especially when over 20 sections, give 236 B.t.u. per sq. ft. or, as the manufacturers represent, 240 B.t.u. per sq. ft. The actual standard unit used in rating steam boilers is ¼-lb. condensation per hr. per sq. ft. of radiation or 240 B.t.u. Hot-water boilers are rated on the basis of 150 B.t.u. per sq. ft. of radiation per hr. If the temperature were the same for the medium, hot water would require no more radiation than steam. The author, for many years, has ceased to lay out hot-water systems to operate at any lower pressures and temperatures than 215 deg. F., as it is useless and unnecessary expense.

10*b*. Determination of Radiation.—Refer to the typical plan of Fig. 7 and the heat-loss schedule of Table 13. The determination of radiation should be independent of the medium, whether steam or water is used, as the only determining factor is the difference in the temperatures of the room and radiator.

The first tabulation *A'* is computed from Diagram 1*B* for 32-in six-tube 4.5 sq ft per section at 215 and 70 deg. and gives 5504 sq. ft. As the temperature is 210 deg instead of 215 deg, from Diagram 1*A* and Table 12 these will be 104.5% or 5751 sq. ft, which is used for Fig. 15

TABLE 12.—CORRECTION FOR RADIATION FOR VARIOUS TEMPERATURES OF THE ROOM AND MEDIUM, PER CENT, PER SQUARE FEET

Room temperature	40 deg.		60 deg.		70 deg.		80 deg.		100 deg.		Room temperature
Radiator temperature	B.t.u.	Percentage	B.t.u.	Percentage	B.t.u.	Percentage	B.t.u.	Percentage	B.t.u.	Percentage	Radiator temperature
160	180	131	153.2	151	138.4	170.4	124.2	190	98.4	240	160
170	197	119.8	170	138.8	154	153	140	168.6	115	205.2	170
180	213	110.8	186.3	126.6	171.4	137.7	157.2	150	127.8	184.7	180
200	250	94.4	223.2	105.7	208.1	113.4	194	121.7	164.7	143.3	200
210	270	87.4	240	98.3	226	104.5	208	113.5	180	131.1	210
215	280	84.3	250	94.4	236	100	215	109.8	187	126.2	215
220	286.8	82.3	260.1	90.7	245.1	96.3	231	100.2	201.6	117	220
240	324.2	72.8	298.5	79.4	284	83.1	269.4	87.6	240	98.3	240
260	364	64.9	338.3	69.8	323.4	73	309.2	76.3	280	84.3	260
280	407.4	58.0	380	62.7	365.8	64.5	351.6	67.1	322.3	73.2	280
300	451.4	52	424.7	55.6	409.8	57.6	395.8	59.6	366.2	64.4	300

The number of sections are shown in column (12), the transmission from Diagram 1 *B* in column (13), the resultant total B.t.u. in columns (11) and (14), and the total square feet in column (15).

If American tube radiation is used, the number of sections in column (12) should be multiplied by 5 instead of 4.5 or $5751 \times \frac{5}{4.5} = 5751 \times 1.11 = 6384$ sq. ft.

If U. S. corporation radiation were used, it would be necessary to purchase $5751 \times \frac{5.5}{4.5} = 5751 \times 1.22 = 7016$ sq. ft.

Schedule *A* is the same as *A'*, only wall radiation or coils are used on the fourth floor with a transmission of 275 B.t.u., giving a total of 5221 sq. ft. at 215 deg. in column (15), Table 13; and multiplied by 104.5% the factor for 210 deg. gives 5455 sq. ft, as used for Fig. 16.

In Schedule *B*, we have 5391 sq. ft. of 38-in. five tube 4.5 sq. ft. per section. For 170 and 70 deg. from Table 12 and Diagram 1*A*, we have 153% or 8248 sq. ft. or the quantity used in Fig. 17.

TABLE 13

Floor	Room	Cubic contents	Wall (W), square feet	Glass (G), square feet	Roof (R), square feet	B.t.u. losses: Room 70 deg., outside temp. 10 deg.						Total B.t.u. (G) + (W) + (I) loss	Radiation at 215 deg., room 70 deg. chart							
						Wall (W), factor 17.6	Glass (G), factor 90	Roof (R), factor 20	Infiltration (I)				Schedule A' 32"-6 tube-4.5 sq. ft. per section—Diagram 1B				Schedule A Wall radiator	Schedule B 38"-5 tube 4 5 sq. ft.		
									Per cent grams to cubic centimeters	Number of changes	B.t.u. (I), factor 1.44									
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9) Table 10	(10) 1.44 × column (1) × column (9)	(11)	(12) Number of section	(13) B.t.u. radiator	(14) Total B.t.u.	(15) Total square feet	(16) Total square feet	(17) Number of section	(18) B.t.u. radiator	(19) Total square feet
	1	34,272	1,790	738	.....	31,504	66,420	......	2.2	.5 × 2	49,352	147,276	6-18	18,100	148,600	666	1-2-3	6-18	18,300	657
													2-20	20,000	....	.....	....	2-19	19,300	
1	2	10,368	441	135	.....	7,762	12,150	......	1-3	.37 × 2	11,232	31,144	1-20	20,000	31,400	140	Floors	1-20	20,300	135
													1-11	11,400	....	.....	....	1-10	10,600	
	3	10,368	441	135	.....	7,762	12,150	......	1-3	.375	5,616	25,528	2-12	12,300	24,600	108	same	2-12	12,500	108
	4	34,272	1,790	738	.....	31,504	66,420	......	2.2	.5 × 2	49,352	147,276	6-18	18,100	148,600	666	as	6-18	18,300	657
													2-20	20,000	....	.....	A'	2-19	19,300	
																	4			
	1	34,272	2,050	465	.....	36,080	41,850	......	1.4	.375	18,500	96,430	1-22	22,000	95,800	423	floor	1-20	20,300	414
													6-12	12,300	....	.....	wall	6-12	12,500	
2	2	10,368	371	205	.....	6,530	18,450	......	2.0	.5	7,465	32,445	2-16	16,200	32,400	144	radiator	2-15	15,400	135
	3	44,640	2,435	670	.....	42,850	60,300	......	1.5	.375	24,100	127,250	7-12	12,300	128,100	567	275	7-12	12,500	558
																	B.t.u.			
													2-21	21,000	....	.....	.....	2-20	20,300	
3	Same as No. 2			...	.....	.....	.....	.....	.....	....	......	256,125	351	......	256,300	1,134	3,848	....	......	1,107
	1	34,272	2,050	465	2,142	36,080	41,850	42,840	1.4	.375	18,500	139,270	4-25	24,600	138,400	630	507	4-24	24,100	621
													2-20	20,000	....	.....	......	2-21	21,300	
4	2	10,368	371	205	648	6,530	18,450	12,960	2.0	.5	7,465	45,405	2-22	29,000	44,000	198	198	2-21	21,300	189
	3	44,640	2,435	670	2,826	42,850	60,300	56,520	1.5	.375	24,100	183,770	4-25	24,600	183,600	828	668	4-24	24,100	810
													6-14	14,200	....	.....	......	6-14	14,500	
									Total B.t.u.....			1,231,969	....	.....	1,231,800	5,504	5,221	....	......	5,391
												Diagram, 1A						Schedule B		
									Schedules A-A' for 210 deg.-70 deg. × 104.5%							5,751	5,455	170 deg.-70		8,248
									Schedule C for 220 deg.-70 deg. × 96.3%							5,300	....	deg. × 153%		

Schedule *C* is used for Fig. 14 and is the same as schedule *A'*, except that the average temperature is 220 deg. instead of 210 deg. Multiplying the radiation in column (15), Table 13, 5504 × 96.3% the factor from Table 12 for 220 deg. instead of 215 deg., we have a total of 5300 sq. ft.

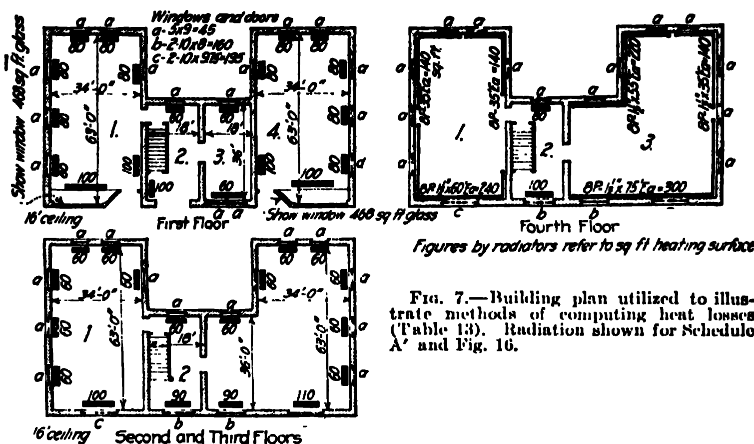


Fig. 7.—Building plan utilized to illustrate methods of computing heat losses (Table 13). Radiation shown for Schedule A' and Fig. 16.

TABLE 13.1. —INFILTRATION BY ALTERNATE METHOD
Windows only on windward sides of building, crack = 1/32 in.

Floor	Room	Cubic contents (Fig. 7)	B.t.u. (*I*) (Table 10)	Size of window and crack	Total length of crack	Factor Table 7	B.t.u. (*I'*)
	1	31,272	18,500	3—9 × 5	3 × 33	96	19,100
				2—10 × 9 75	2 × 50		
2	2	10,368	7,465	2 -8 × 10	2 × 11	96	8,448
	3	11,640	24,100	3 9 × 5	3 × 33	96	27,550
				2 8 × 10	2 × 50		
Total...	.. ...	. ..	50,065	2 10 × 9 75	2 × 44	..	55,098

Roof. (3-in. (1½-in hung ceiling with

$$U = \frac{1}{\frac{1}{1.3} + \frac{1}{4.2} + \frac{3}{8.3} + \frac{0.125}{0.4} + \frac{2}{0.93} + \frac{1.5}{8}} = 0.25$$

Heat loss per sq. ft = 0 25 × 80 = 20 B.t u.

Walls. (12-in. concrete, 2-in hollow tile)

$$U = \frac{1}{\frac{1}{5.2} + \frac{1}{0.93} + \frac{1}{1.3} + \frac{1}{0.99} + \frac{12}{8.3}} = 0.222$$

Heat loss per sq. ft. = 0.222 × 80 = 17 6 B.t u

All these layouts would require the same grate, chimney, and a like amount of heating surface in the boiler although with widely varying quantities of direct radiation. These principles used in computing the schedules apply to all buildings and dwellings with heating surface directly connected to the boiler or heat source. Ready comparison may be made as to the actual effect of different assumptions on the ultimate solution.

The roof and wall construction are assumed and heat losses figured. The radiators marked on the plan (Fig. 7) are for the first condition of water or steam at 210 deg. F. and 70 deg. F. in the rooms, and −10 deg. F. outside. No allowance is made for exposure and the infiltration loss is calculated by two methods which show about 10% difference in results. This is well within the error of the assumptions.

It is always safe to increase the air change to at least 1 per hour where doors open directly out of doors. This was done in the example under consideration. The theory of air leakage would not hold under these conditions. It is also well to reduce the air change on the top floor, especially if elevator doors open into the room. These shafts create a natural draft tending to take the heated air from the lower floors overheating the top floor. The heat losses were determined regardless of the type of system or type of radiator, as they would be the same in any case.

10c. Radiators.—The heat losses of the building and rooms are compensated by radiators of various types. Radiators when placed directly in the rooms are known as direct radiators. When placed in a central location and supplied with air ducts, they are known as indirect radiators, the air being supplied either by a fan or by gravity circulation. Radiators with an out-door connection through the wall are known as direct indirect radiators.

Column Radiators. These are built up of sections of various heights put together with screw or push nipples. The sections are known as leg and loop sections. Each screw nipple has two lugs which engage a mandril so that the sections and corresponding nipples which have right and left threads may be screwed together. Round paper gaskets are placed between the sections. The push nipples are machined and sections pressed together and through bolts are put in to hold the sections in place.

There are also special column radiators known as circular, corner, stairway, and hot closet. These may have extra high legs or be legless and supported on wall brackets.

All cast-iron radiators have top and bottom connections, whether used for steam or for water, All manufacturers are making three-, four-, five-, six-tube radiators 20 in., 23 in., 26 in., 32 in.. and 38 in. in height with 2½-in centers per section. Some make seven-tube radiators with 3- and 2½-in. centers, these last being made 14 in., 17 in., and 20 in. high for use as a window type.

The manufacturers have varied the size of sections slightly but have a wide range in rated catalogue square feet, so that it is rather dangerous to use the catalogue square feet, as a wide range in the number of sections in the final installation will result.

Diagram 1B is especially prepared to eliminate this discrepancy and give a comparison in unit of heating value with the former column radiation.

Sheet-metal Radiators. -These are almost universally made of brass or aluminum. They weight less than 2 lb. per sq. ft. of surface instead of 7 lb. per sq. ft. for the cast iron.

There are several made of brass pipe with fins of brass, as that of the Train Company, also one by Rome Brass and Copper Company which is two sheets of brass spot welded and the sheets between welds formed into tubes by forcing the plates apart with high pressure of 1000 lb. per sq. in. All the present brass sheet-metal radiators will stand almost any pressure. There is no way of gaging the square feet of equivalent radiation, as the action is almost entirely by convection.

The engineer has no means of checking the capacity of these radiators and is almost solely dependent on the tabulated radiator tests of the manufacturers. There are so many attendant conditions entering the installation of these radiators that a liberal allowance should be made.

The weight f cast iron is a serious objection, especially for use in high buildings, as the weights have to be carefully determined. Where caisson work to bed rock is necessary, a reduction of 500,000 lb. weight in 100,000 sq. ft. of radiation may be made by the use of sheet metal instead of cast iron. This saving in weight is equivalent to an increas f 2500 sq ft. or a space 50 × 50 ft. of floor space for the same foundation, estimating 200 lb. per sq. ft. load on the f datı

A great deal has been said about corrosion in pressed-steel radiators, but if pure metal is used, and the radiators can be thoroughly drained, there is no danger. On hot-water systems with the water unchanged, these radiators will last indefinitely, as the water acts as a preservative to the iron when all air is removed.

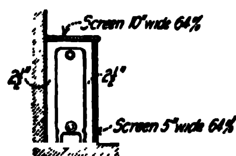


Fig. 8.—Enclosure for concealed direct radiation.

The present sheet-metal radiator with only 40-lb. test pressure is very limited in its use. Cast-iron radiators are tested to 80-lb. pressure, and where higher pressures are desired, the metal thickness may be increased to stand any desired pressure. The weight and cost, however, is increased in proportion to the thickness.

Enclosed Radiators.—Enclosed radiators should be increased in amount of surface from 15 to 25% depending upon the type of enclosure. From tests by Harding and Lichty, at the University of Illinois, the effect of shelves was to reduce the transmission 5% and, if very close to the top of the radiators, 10%. Recessed radiators, 2½ in. from the wall on the back, were reduced 10%. The most efficient type of enclosure, reducing the efficiency to 80% of the open radiator, is shown in Fig. 8. Enclosed radiators, however, are to be avoided if possible.

On pages 1187 and 1188, Diagrams 5 and 6 provide methods of computation for exactly determining the transmission for enclosed radiators of the type in Fig. 8.

The transmission of direct radiators exposed is 1.6 to 1.8 B.t.u. per deg. difference per sq. ft. per hour between the convected air and the medium.

This corresponds to a velocity of 100 ft. to 150 ft. per min from Diagram 5. By means of Diagram 6, we can determine the net area of the grills and the rise in temperature of the convected air.

Example.—If the radiator used is 3 sq. ft. per section spaced $2\frac{1}{2}$ in and the grill has a 64 % area with 10 in. width, the area per section will be 6.4 in $\times 2\frac{1}{2}$ = 13.12 sq in per section. Then 13.12/144 = 0.091 sq. ft for 3 sq. ft. of heating surface. The 3.00/0.091 = 33 or the factor *f* used in Diagram 6.

If the grill is the full height of the radiator, take one-half the net area, or if it is 15 in high with 64 % net area, the factor *f* would be 0.64×15 in $\times 2\frac{1}{2}$ in/2 = 12 sq in net

$$\frac{12}{144} = 0.083 \text{ sq ft net per section} \quad \frac{3}{0.083} = 36 = f$$

The area is divided by 2 on account of requiring space for the ingress of the cold air and egress of the warm air.

We will assume *f* as 33 and a temperature of 215 deg for the steam or water and 65 deg for the room with a heat loss of 15,000 B.t.u. Then $\theta_s - \theta_1$ = 150 deg and a velocity of 100 ft per min. We obtain from Diagram 6, $(\theta_s - \theta_1) = 95$ deg.

$(\theta_s - \theta_1) - (\theta_s - \theta_2) = \theta_2 - \theta_1 = 150 - 95 = 55$ deg rise in the temperature of the air.

The specific heat of air being 0.24 and weight per cu ft 0.075 lb., we have the B.t.u. per square foot clear area at 100 ft. velocity. 100 ft. 1' $\times$ 60 min. $\times$ 0.24 $\times$ 0.075 lb. = 108 B.t.u. per deg. difference per hour.

108 $\times$ 55 deg. = 5940 B.t.u. per sq. ft of area.

$$\frac{15{,}000 \text{ B.t.u.}}{5940} = 2.6 \text{ sq ft}$$

The square foot of radiation per square feet of area is 33, so 2.6 $\times$ 33 = 85.8 sq. ft. With 3 ft. per section, 85.8/3 = 28 sections of, say, 17-in seven tube. This radiator from Diagram 1*B* has a transmission exposed of

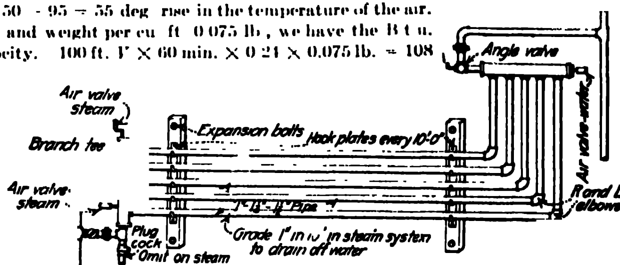


Fig. 9.—Header coil.

2 $\times$ 9800 B.t.u. or the transmission of two 14-section radiators or 19,600 B.t.u. and $\frac{15{,}000}{19{,}600}$ = 80 % efficiency of the exposed radiator.

By determining the clear area per unit of length of the area and the square foot of radiation for the same unit of length, the factor *f* or the square foot of heating surface per square feet of area is determined from Diagram 6.

10d. Pipe Coils. Pipe coils are the most efficient form of heating surface and when constructed properly, are really better and less offensive looking than radiators, but high labor costs and the cheapness of cast-iron radiators have caused them to be superseded except in cases where long coils may be utilized, as in factory work, thus reducing the labor cost for connections.

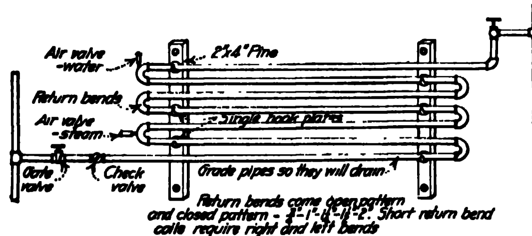


Fig. 10.—Return bend coil.

Two types of coils are shown in Figs. 9 and 10, one known as the header coil and the other as a return bend coil. The vertical pipes shown are for the purpose of taking up expansion. The same object may be accomplished by fitting the coil into a corner of the building, in which case the vertical pipes and headers become unnecessary. The shortest pipe in the spring piece should not be less than 3 ft. Return bend coils are used where breaks in the the wall prevent the us of long coils. When the pipes are so short as to prevent the swing of the return bend in screwing them on the pipe, right and left threaded bends are used generally for coils under 10 ft. long. A box coil is made from a series of return bend coils screwed into two headers at the ends. With header and return bends an infinite number of combinations may be made in coil work.

Coils are often placed overhead in factory work to get them out of the way. Since heated air rises, the heat has to back down to about 6 ft from the floor before the heating effect is obtained. This means the coils are in a temperature 10 or 15 deg. higher than the average room temperature. Where used on ground floors with open doors,

it has been found difficult to get the first floor warm as most of the heat was dissipated in raising the temperature of the floor above. Where there are moving belts, and where high pressure steam is used with corresponding high temperatures, fairly good results are obtained.

The best position for pipe coils is on the side wall under the windows. Wall radiators are often used as substitutes for coils and this was the purpose of their original design.

10e. Location of Radiators.—As a general rule, the best location for radiators is under the windows or against an outside wall. The radiator transmission will be greater if placed on the outside wall due to the cooling effect of the window accelerating the upward and downward flow along the ceiling from the radiator, thus increasing the velocity of the air and the heat transmission by convection.

Persons sitting at the window will feel a disagreeable draft due to the cooling effect of the cold glass surface on the downward current of air, but if a radiator is placed under the window, the heat by convection from the radiator neutralises the downward air current over the cold glass, thus reducing the air movement materially in the room and therefore counteracting the draft. However, both of these effects are small as compared with the possible and probable errors of assumption in computing the heat losses and square feet of radiation.

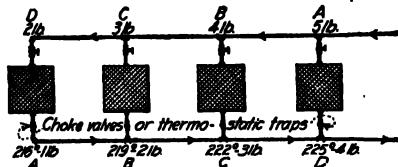


Fig. 11.—Diagram showing distances unbalanced, with supply and return flowing in opposite directions, causing the cooling increments to be positive and negative.

11. Principles of Piping.—Figs. 11, 12, and 13 show diagrammatically principles that, if observed, will facilitate the solution of the problem of proper pipe sizes for steam and water systems and insure better results in operation.

Fig. 11 is the generally accepted method of laying out steam and water systems. Thermostatic traps or choke valves are absolutely necessary to insure operation when the piping is arranged in this manner. With the same work in each radiator and the same drop per unit of distance, without the thermostatic traps the fluid would actually be required to flow up hill

Table 14.—Size of Steam Mains for 1 to 3-lb. Average Pressure

Loss in pressure per 100 ft. run in oz. per sq. in. Steam in lb. per hr. Divide by condensation factor for sq. ft. of radiation. Plotted on Diagram 2

Velocity (ft. per sec.)	10 ft.		20 ft.		30 ft.		40 ft.		50 ft.		60 ft.		70 ft.	
Nominal pipe sizes (inches)	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour
3/4	0.56	4.8	2.24	9.6	5.04	14.4	9.0*	19.2	14.0	24.5	20.2	29	27.5	33.6
1	0.39	7.5	1.55	15.0	3.44	22.5	6.08	30.0	10.0	37.5	14.4	45	19.6	52.5
1 1/4	0.29	11.6	1.14	23.2	2.6	34.8	6.64	46.0	7.25	58.0	10.44	70	14.28	81.0
1 1/2	0.205	16.8	0.82	33.6	1.8	50.4	3.28	67.0	5.0	84.0	7.2	100	9.8	118.0
2			0.48	60.0	1.09	90.0	1.92	120.0	3.14	150.0	4.36	180	5.88	210.0
2 1/2			0.34	92.8	0.76	139.5	1.34	186.0	2.11	232.0	3.04	278	4.1	326.0
3			0.25	134.0	0.56	200.7	1.0	267.0	1.56	334.0	2.25	401	3.06	468.0
3 1/2				182.0	0.48	274.0	0.82	365.0	1.32	456.0	1.9	547	2.56	638.0
4					0.37	357.0	0.66	476.0	1.04	595.0	1.5	714	2.04	833.0
4 1/2							0.53	602.0	0.82	752.0	1.2	902	1.64	1,052.0
5							0.48	744.0	0.75	930.0	1.08	1,116	1.47	1,302.0
6							0.39	1,073.0	0.56	1,341.0	0.83	1,609	1.13	1,877.0
7							0.29	1,460.0	0.45	1,825.0	0.65	2,190	0.88	2,555.0
8							0.25	1,908.0	0.39	2,385.0	0.56	2,862	0.76	3,339.0
9									0.33	3,021.0	0.47	3,624	0.64	4,228.0
10									0.3	3,720.0	0.43	4,464	0.58	5,208.0
12									0.26	5,370.0	0.34	6,444	0.46	7,518.0
14											0.28	.5,844	0.38	10,227.0
16											0.24	11,493	0.32	13,356.0

or from a lower to a higher pressure or temperature. There would be in any case, a retardation of the flow and this is frequently the cause of trouble on heating systems, although somewhat exaggerated in the sketch. By observing the above principles, errors of calculation and assumption are largely eliminated and adjustments of flow after installation are avoided.

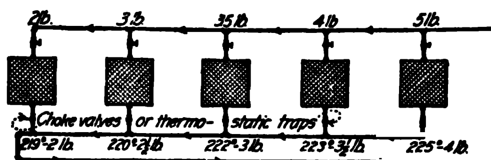


Fig. 12.—Method of balancing distances on piping for steam or water. Cooling increments are always positive, and return and supply flow in the same direction.

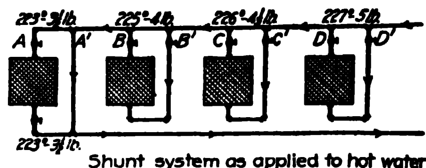


Fig. 13.—Cooling increments all positive, distances balanced.

In Figs. 12 and 13 all radiators are exactly the same distance from the source and the cooling increments are all in the same direction or added in the direction of the flow. Fig. 13 is a method applying to hot water systems whereby the radiators are shunted, although the radiators at *A* may be somewhat cooler than those at *B*; it is readily seen that all cooling effects are in the same direction, and as the average mean temperature is used, it will have little effect on the system. In Fig. 13 all tees are full size on the run which has a great deal to do with reducing friction, as reducing tees offer the greatest obstruction to flow. This defect does not appear in systems of steam and water with low velocities. All pipes should also be carefully reamed to remove the burr, as sometimes ¼ in. of the diameter is lost where the burr is left.

The principle involved in a shunt circuit may be stated as follows. The drop in pressure between *B'* and *B* is the same through the radiator as through the main. The quantity of water flowing from *C'* to *B'* is the same as from *B'* to *B* through both passages (Fig. 13). From formula of Art. 9 for loss of head in friction

$$\frac{lV^2}{d} = \frac{l_1V_1^2}{d_1}$$

in which lV and d refer to the main (BB'), and l_1, V_1, and d_1 to the shunt (BB'). This formula gives the relation between the velocities in the two circuits between *B* and *B'* and makes possible the solution of the proper size of pipes for any required flow

Table 14 (continued)

80 ft.		90 ft.		100 ft.		110 ft.		120 ft.		130 ft.		1 oz. drop	
Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Oz. drop	Lb. per hour	Velocity	Lb. per 1-oz. drop
36.0	38.4	45.4	43 2	56 0	48	.....	....	....	......	....	......	13 2	6.2
25.6	60.0	32.4	67 5	40 0	75	....	....	....	......	....	......	15.8	12.0
18.6	92.8	23.5	104.4	29.0	116	.....	.. . ..	....	......	....	......	18 5	22.0
12.8	134.4	16.2	160.2	20.0	168	24.8	184.8	....	......	....	......	22 5	37 2
7.68	240.0	10.17	270.0	12.6	300	15.25	330.0	....	......	....	......	29 0	86.0
5.4	371.0	6 8	418.5	8.4	465	10.21	511.5	....	......	...	....	34.5	160 0
4 0	534.0	5.06	602.1	6.24	669	7.55	735.9	....	......	....	.....	40.0	267.0
3.3	730 0	4 21	821 0	5.3	912	6.4	1,003.0	7.6	1,094	9.0	1,186	43 4	400.0
2.64	952 0	3.33	1,071.0	4.16	1,190	5.04	1,309.0	5.9	1,428	7 03	1,547	49.0	585 0
2 13	1,203 0	2.7	1,354.0	3.3	1,504	4.22	1,654.0	4.8	1,804	5.6	1,955	54.8	830.0
1.92	1,488.0	2.43	1,674.0	3.0	1,861	3.68	2,046.0	4.32	2,232	5.12	2,418	58 0	1,080.0
1.47	2,146.0	1.87	2,414.0	2.3	2,682	2.78	2,950.0	3.32	3,218	3 84	3,486	66.0	1,770.0
1.15	2,920.0	1.46	3,285.0	1.8	3,650	2.19	4,015.0	2.60	4,380	3 04	4,745	74 3	2,712.0
1.0	3,816.0	1.25	4,293.0	1.55	4,770	1.86	5,247.0	2.25	5,724	3.62	6,201	80.0	3,810.0
0.84	4,833.0	1.06	5,437.0	1.3	6,041	1.58	6,646.0	1.87	7,249	2.2	7,853	87.4	5,280.0
0.76	5,952.0	0.96	6,696.0	1 2	7,440	1.44	8,184.0	1.71	8,928	2.0	9,672	92.0	6,870.0
0.61	8,592.0	0.76	9,666.0	0.95	10,740	1.15	11,814 0	1.36	12,888	1.6	13,962	103 0	11,100.0
0.50	11,688.0	0.64	13,149.0	0.784	14,610	0.95	16,071.0	1.14	17,532	1.34	18,993	113.0	16,590.0
0 42	15,264.0	0.53	17,172.0	0.66	19,080	0.80	20,988.0	0.96	22,986	1.12	24,894	123.0	23,490.0

12. Low Pressure Gravity Steam System.—The boiler on this type of system is connected to the radiators by a series of supply and return pipes, arranged so that the condensation flows back to the boiler by gravity. Radiators may be connected with single pipe risers and runouts or with separate supply and returns, known as one and two pipe systems of piping.

All steam systems connected in direct circuit with the boiler require a head of water in the vertical return as it enters, to counterbalance the difference in pressure in the boiler and radiation due to the condensation of the steam and friction of the fluid. This necessitates a difference in level between the lowest dry return pipe and the water line of the boiler of 2 ft. for each 1 lb. difference in pressure, or, in most cases, 3 or 4 ft. The greater the initial pressure carried, the greater the difference in level required. If the dry return is too close to the water line, water will collect in the horizontal pipe, and failing to return, will cause low water in the boiler. If the boiler pressure is lowered, the necessary counterbalancing head in the return is also reduced and the water will flow back to the boiler. The job, however, should be designed so this will not occur or it should be remedied by raising the return or lowering the boiler. Returns are known as wet and dry. Those above the water line carry very wet steam and water, and those below the water line, known as wet returns, carry water only.

12a. Size of Steam Pipes.—Diagram 2 and Table 14 may be used for the steam lines on all low pressure steam systems from atmosphere to 10-lb. pressure. Their use will give somewhat greater capacity at the higher pressures due to the increase of the density of the steam. Diagram 2 shows two sets of lines, one dash and one full. The dash lines refer to the

Fig. 14.—Low pressure steam, 1-lb. to 5-lb. pressure, 220 deg. F., Schedule "C" (Table 13), overhead down feed. one and two pipe; also one and two pipe up feed.

lower scale for pounds of steam, and the full lines to the upper scale, which is 100 times the lower. The pressure drop per 100 lin. ft. is in pounds per square inch, and dotted lines show equal pressure drop in ounces per square inch per 100 lin. ft. In order to use this diagram and table it is necessary to know (1) the pounds of steam per hour (determined from the heat loss of the building plus 25% divided by the latent heat of evaporation), and (2) the friction head (drop) in pounds per square inch per 100-ft. length (determined from the maximum allowable friction head divided by the length of the circuit). If the piping is arranged in the proper manner, the branch circuits may be designed from the equalization table, Table 15.

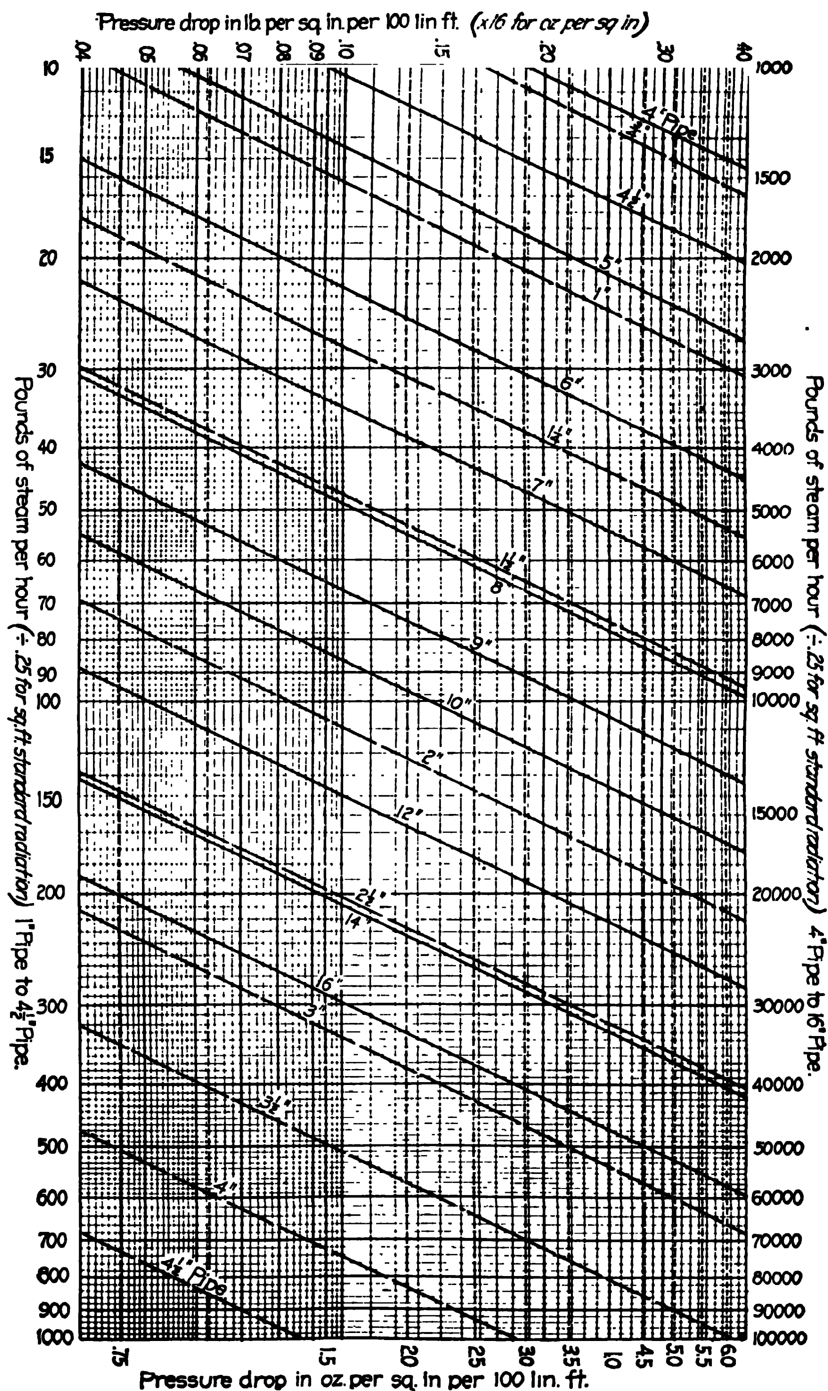


DIAGRAM 2.—Capacities and pressure drop in standard pipes. Steam under 5-lb. mean pressure.

TABLE 15.—TABLE OF NUMBER OF PIPES OF EQUIVALENT AREA, ALSO NUMBER HAVING THE SAME DISCHARGE FOR SAME LENGTH (¾ IN. TO 12 IN.)

Ratio Velocity	Ratio Area		¾	1"	1¼"	1½"	2"	2½"	3"	3½"	4"	% Ratio Areas	% Ratio Velocity
18%	550%	12	1163.0 / 212.00	606.0 / 131.0	296.4 / 75.5	197.6 / 55.5	102.6 / 33.7	64.6 / 23.7	36.4 / 15.3	24.4 / 11.45	17.8 / 8.85	200%	50%
20%	500%	10	721.3 / 148.0	376.0 / 91.4	183.4 / 52.6	122.6 / 38.8	63.6 / 23.5	40.1 / 16.3	22.6 / 10.7	15.11 / 8.0	11.11 / 6.2		
		9	545.6 / 118.0	284.4 / 72.8	140.0 / 42.0	92.7 / 30.8	48.1 / 19.0	30.3 / 13.14	17.07 / 8.5	11.43 / 6.35	8.33 / 4.93		
		8	397.7 / 94.0	207.0 / 58.0	101.0 / 33.5	67.6 / 24.6	35.0 / 15.0	22.1 / 10.5	12.44 / 6.8	8.33 / 5.07	6.07 / 3.93	150%	67½%
25%	400%	7	283.9 / 72.6	148.0 / 45.0	72.1 / 26.0	48.2 / 19.0	25.0 / 11.5	15.8 / 8.15	8.9 / 5.25	5.95 / 3.92	4.33 / 3.04		
		6	192.8 / 54.2	100.5 / 33.4	49.0 / 19.3	32.8 / 14.2	17.1 / 8.6	10.7 / 6.05	6.03 / 3.9	4.04 / 2.92	2.94 / 2.26		
		5	118.7 / 37.6	61.9 / 23.2	30.2 / 13.4	20.2 / 9.84	10.5 / 6.0	6.6 / 4.2	3.72 / 2.72	2.5 / 2.02	1.81 / 1.57		
33%	300%	4½	88.14 / 29.9	46.0 / 18.5	22.4 / 10.7	15.0 / 7.95	7.8 / 4.75	4.9 / 3.34	2.76 / 2.16	1.86 / 1.61	1.34 / 1.25		
		4	65.5 / 23.9	34.15 / 14.75	16.64 / 8.5	11.13 / 6.25	5.8 / 3.8	3.63 / 2.7	2.05 / 1.59	1.37 / 1.3	1	100%	100%
40%	250%	3½	47.7 / 18.5	24.9 / 11.43	12.13 / 6.6	8.1 / 4.85	4.21 / 2.94	2.65 / 2.06	1.5 / 1.33	1	12"	150%	67.5%
		3	32.0 / 13.85	16.7 / 8.6	8.12 / 4.9	5.43 / 3.63	2.82 / 2.2	1.78 / 1.55	1	1.61 / 1.44	10"		
50%	200%	2½	18.0 / 8.96	9.4 / 5.54	4.57 / 3.2	3.06 / 2.35	1.6 / 1.42	1	1.32 / 1.25	2.13 / 1.8	9"		
		2	11.35 / 6.3	5.92 / 3.9	2.9 / 2.24	1.93 / 1.65	1	1.37 / 1.25	1.81 / 1.58	2.92 / 2.26	8"		
67%	150%	1½	5.9 / 3.8	3.07 / 2.4	1.5 / 1.36	1	1.4 / 1.29	1.92 / 1.62	2.54 / 2.03	4.1 / 2.9	7"		
		1¼	3.94 / 2.8	2.05 / 1.73	1	1.47 / 1.34	2.06 / 1.73	2.83 / 2.18	3.74 / 2.73	6.03 / 3.9	6"		
		1"	1.92 / 1.62	1	1.62 / 1.44	2.4 / 1.94	3.35 / 2.5	4.6 / 3.14	6.07 / 3.94	9.8 / 5.65	5"		
		¾"	1	1.35 / 1.26	2.24 / 1.81	3.22 / 2.43	4.51 / 3.14	6.19 / 3.93	8.18 / 4.95	13.2 / 7.1	4½"		
Ratio Velocity	Ratio Area		4½	5"	6"	7"	8"	9"	10"	12"		% Ratio Areas	% Ratio Velocity

12b. Size of Return Pipes.—James A. Donnelly has deduced the sizes of return pipes for various systems as shown in Table 16. The theoretical size of return main in any steam heating system will depend upon (1) the allowable pressure drop in the main, usually taken the same as for the steam main, and (2) upon whether the main is wet (run below the water line of boiler) or dry (run above the water line of the boiler). In the case of wet returns the main carries only water. Assuming the same friction pressure loss as for steam and with water flowing in the pipes, the weight will vary as the square root of the densities for same pressure drop and pipe size, or a wet return has 40 times the capacity of a dry return. These capacities are given in square feet of radiation at 0.3 lb. per sq. ft. per hr. as the condensation factor.

TABLE 16.—MAXIMUM CAPACITY OF STEAM AND RETURN MAINS FOR RUNS OF MODERATE LENGTH[1]

In this table the maximum capacity of return mains is given for various percentages of steam carried, as well as the steam rating of pipes from ½ to 16 in. These quantities are all figured for a drop in pressure of 1 oz. per sq. in., per 100 ft. in straight pipe and are expressed in sq. ft. of radiation with a condensation factor of 0.3 lb. per sq. ft. per hour.

Size (in.)	A Steam rating (Dry steam)	B Wet return (Column "A" × 40)	C 2½ % steam (Column "A"×20)	D 5 % steam (Column "A"×13½)	E 7½ % steam (Column "A" × 10)	F 10 % steam (Column "A" × 8)	G 15 % steam (Column "A"×5.7)	H 20 % steam (Column "A" × 4.4)
½	5	200	100	67.5	50	40	27	22
¾	20	800	400	270	200	160	114	88
1	40	1,600	800	540	400	320	228	176
1¼	75	3,000	1,500	1,012	750	600	427	330
1½	150	6,000	3,000	2,024	1,500	1,200	855	660
2	300	12,000	6,000	4,050	3,000	2,400	1,710	1,320
2½	500	20,000	10,000	6,750	5,000	4,000	2,850	2,200
3	960	36,000	18,000	12,150	9,000	7,200	5,130	3,960
3½	1,500	60,000	30,000	20,250	15,000	12,000	8,550	6,600
4	2,000	80,000	40,000	27,000	20,000	16,000	11,400	8,800
4½	2,800	.....	56,000	37,800	28,000	22,400	15,060	12,320
5	3,600		......	48,600	36,000	28,800	20,520	15,840
6	6,000			.	60,000	48,000	34,200	26,400
7	9,000				.	72,000	51,300	39,600
8	13,000				.	......	71,000	57,200
9	18,000	.....	..	.	...	......	......	79,200
10	23,000							
12	37,000							
14	55,000							
16	78,000							

[1] By James A. Donnelly.

Column "A," steam rating in standard direct radiation for piping within buildings for all classes of systems.
Column "B," rating for wet return main of a gravity system.
Column "C," rating for main return of the positive differential system.
Column "D," rating for the main return when it is above the water line in a dry return gravity system.
Column "E," rating for the branch returns of the positive differential system, and for the branch returns that are above the water line in a wet return gravity system.
Column "F," rating for the branch returns of a dry return gravity system.
Columns "G" and "H," rating for gravity systems where the returns have unusual condensing capacity and for the returns in vacuum systems where jet water is used.

If it is desired to apportion the sizes more accurately, follow each circuit and branch with the distances, reading the drops from the discharge on Diagram 2. The sum of the drops for flow on all circuits, drawing a line from boiler through the radiator and back, should all equal the same total sum of 2-oz. drop per 100 ft. or a total of 8 oz. All risers and mains should be dripped and checks or thermostatic traps placed at points marked "A" in Fig. 14.

12c. Illustrative Problem.—Fig. 14 is a steam piping layout. One-half of the building has a one-pipe up feed and the other half an overhead down feed piping system. Practically 220 deg. average, or 2 to 5-lb. steam pressure is used. From Fig 7 and Table 13, B.t.u. losses per hour = 1,232,000 + 25% = 1,540,000 B.t.u. Divide by the latent heat of steam at 220 deg. F., or 956 B.t.u. $\frac{1{,}540{,}000}{965} = 1600$ lb. of steam per hr. with 5310 sq. ft. of surface (schedule "C"). The length of the circuit on the overhead system will be 400 ft. The available drop in pressure in feet of water is equal to the difference between the height of the water line in the boiler and the height of the water in the return main—say 18 in. of water column, or, with 0.43 lb. per ft. = 1.5 × 0.43 = 0.645 lb. or 0.645 × 16 = 10.32 oz. $\frac{10.32 \times 100}{400} = 2.6$-oz. drop in pressure per 100 ft.—say 2 oz. to be conservative. If there are 5300 sq. ft. of surface, 1600 lb. of steam per hr., and 2 oz. drop per 100-ft. run, we have $\frac{1600}{5300} = 0.3$ lb. of steam per sq. ft. of heating surface per hr. In Diagram 2, use the line of 2-oz. drop which shows a 5-in. main will be large enough. If we assume 1-oz. drop per 100 ft., it will require a 6-in. line. Use a 5-in. line with covered risers, or a 6-in. line uncovered.

As the total heat loss of the building was used, the point of capacity for covered or uncovered pipes is not so important, as the greater radiation will reduce the pressure required to heat the building, increasing the drop and velocity.

The 5-in. main, being divided into 2 branches, Table 15 shows 1.8 of 4-in. pipes equal a 5-in. pipe and, therefore, two 4-in. branches will be a little larger than the 5-in. main. A 4 in. has 65.5 times the capacity of a ¾-in. pipe (Table 15). For one-half the surface, or 2650 sq. ft, $\frac{2650}{65.5} = 40.6$ ¾-in. pipes or $\frac{40.6 \times 100}{2650} = 1.53$ of ¾-in. pipes per 100 sq. ft. of surface. Riser 1 has 260 sq ft ; therefore, 2.60 × 1.52 = 4.0 of ¾-in. pipes, or one 1½-in. pipe (Table 15). Riser 2 has 305 sq ft ; therefore, 3.05 × 1.52 = 4.7 of ¾-in. pipes, or one 1½-in. pipe, etc. For return pipe, use Table 16, Column F

For one-pipe up feed system, double the riser connections in size as there will be water and steam flowing in opposite directions—that is, use 3.2 of ¾-in. pipes per 100 sq. ft. for riser and 1.52 of ¾-in. pipes per 100 sq. ft. for steam main.

Fig. 14 is intended to show diagrammatically different methods of connecting risers and radiators applicable to all steam, vacuum and vapor systems The use of automatic vents and thermo-traps would form a vapor system when connected directly to boilers; with mechanical air removal and traps and pumps would be a vacuum system; with all appliances left off and directly to boiler would be a gravity return system.

13. Forced Hot Water System.- Diagram 3 is the result of a comparison of more than seven friction formulas published by the writer in *Power*, July 9, 1912. The average seemed to agree nearest to William and Hazen's formula:

$$H = 0.000371 l \frac{(V)^{1.85}}{(d)^{1.166}}$$

H = friction head, feet of water.
l = length in feet.
V = velocity, in feet per second.
d = diameter of pipe, in feet.

If all units are equidistant from the source in the layout of any piping system, the length in the formula may be disregarded as the distances are balances.

In any case, no matter how complicated the piping system, the head through all circuits and fluid passages will be the same, and the velocity of the flows will adjust itself accordingly. It often occurs that with some layouts the problem becomes indeterminate, and these constructions should be avoided by reducing to a minimum the number of passages for the fluid. Effort should be made to avoid complicated systems requiring accurate determination of the drop and to so plan the circuits that they will give the proportional flow required for each branch, with a minimum of computation.

13a. Pumps for Forced Hot Water Systems.—On large plants two pumps should be used, one electric and one steam driven. If these pumps have a rating for the total capacity of the system, they should be placed in series; if the rated capacity is ½ of the maximum or less, they should be placed in parallel.

The pumps should be double suction with hollow impeller, preferably of brass or bronze, with water packed bearings.

$$\frac{\text{B.t.u. per hr.} \times 7.5}{\text{Temp. drop} \times 60 \text{ min.} \times \text{wt. per cu. ft. at mean temp.}} = \text{gallons per min., pump capacity}$$

$$\frac{\text{Gal., per min.} \times h \times 8.3 \text{ lb.}}{33{,}000 \times \text{eff. (50 to 70\%)}} = \text{brake horsepower of prime mover}$$

in which h = total friction head plus safety factor in feet.

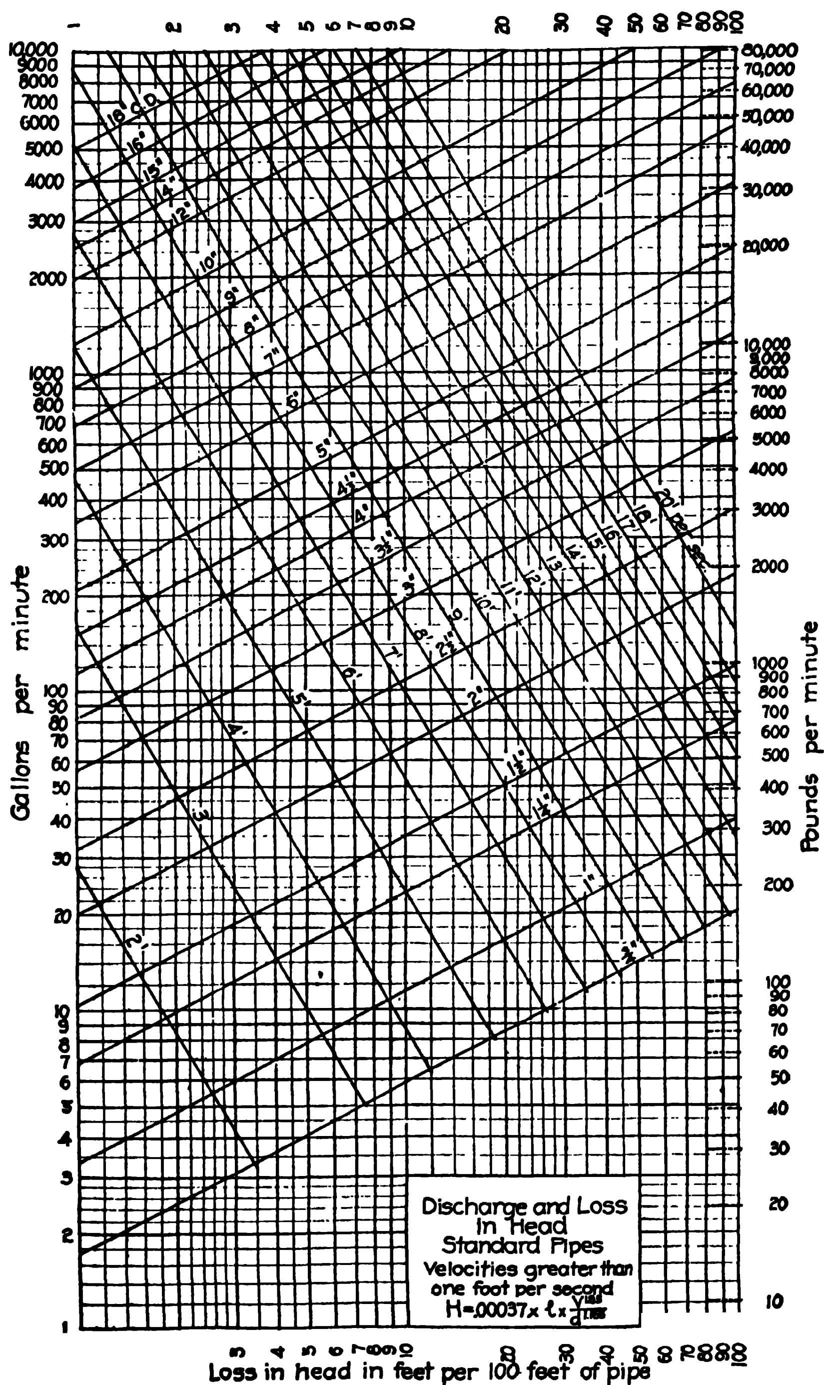

Gallons per minute
Pounds per minute
Loss in head in feet per 100 feet of pipe
Discharge and Loss
In Head
Standard Pipes
Velocities greater than
one foot per second
H=.00037 x ℓ x V^1.86/d^1.25
18" O.D.
16"
15"
14"
12"
10"
9"
8"
7"
6"
5"
4½"
4"
3½"
3"
2½"
2"
1½"
1¼"
1"
¾"

DIAGRAM 3.

After calculation of required quantities, the nearest size frame built by the manufacturer should be determined and the layout adjusted accordingly.

The curves of these pumps are such that when the head reaches the maximum point, the discharge falls off to nothing at the rated speed, or the discharge increases to a certain point and cannot be increased except by an increase in speed.

If the friction on the piping for a certain capacity is greater than the rated head on the pump, the discharge will be reduced. If the friction is less, the discharge will increase until there is a balance and the motor is apt to overload due to the increased horsepower.

When the head on the gages shows the same as the rated head of the pump, the pump may not be delivering the water. There are a large number of installations where the water delivered is not even near the capacity of the pump. It is good practice when using motor driven pumps in places where they receive little attention, to specify a Cutler Hammer overload release so the motor will be thrown out of circuit automatically when overloaded.

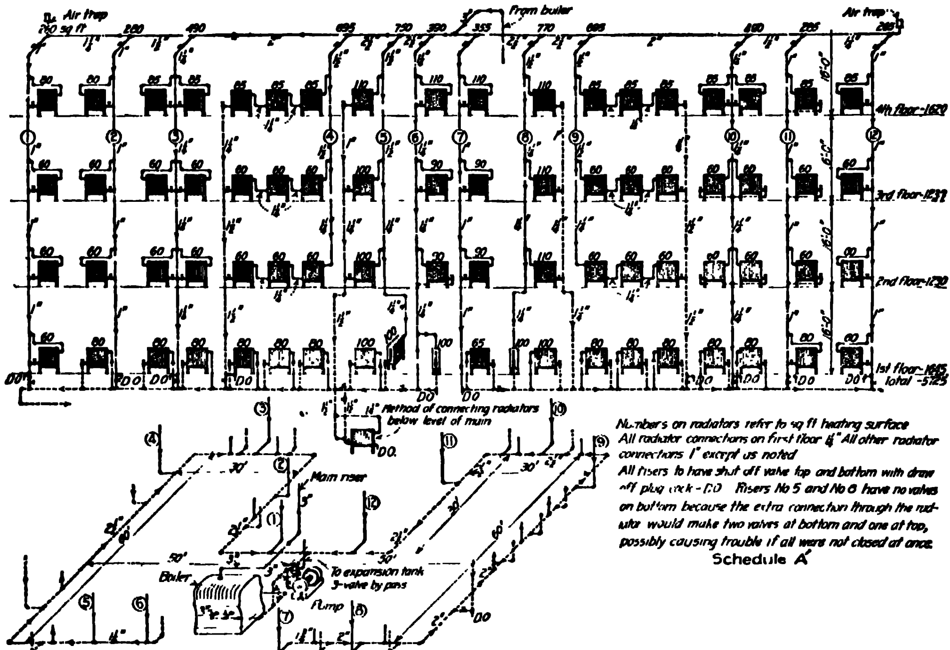


Fig. 15.—Overhead forced hot water system layout, 210 deg. average temperature, 20 deg. drop, Schedule "A", (Table 13).

13b. Illustrative Problem.—*Overhead Piping* (Fig. 15).—210 deg. F. average—20 deg. drop. W = 59.8 lb. per cu. ft. Total length of circuit is 450 ft. (From Table 2, p. 1081, Column 6).

Total B.t.u.	1,232,000
25%	308,000
Total	1,540,000 B.t u. per hr. (Table 13)

$$\frac{1,540,000}{60 \text{ min.} \times 20 \text{ deg.} \times 59.8} \quad 21.5 \text{ cu. ft. per min.} \times 7.5 = 162 \text{ gal. per min.}$$

Table 13, schedule "A" gives 5788 square feet of 3-column radiators for this layout.

$$\text{Water per sq. ft.} = \frac{162.0}{5725} = 0.028 \text{ gal. per sq. ft. or } 2.81 \text{ gal. per 100 sq. ft. per min.}$$

Assume 35-ft. head for total lift for friction.

$$\frac{162 \times 8.3 \text{ lb.} \times 35}{33,000 \text{ ft.-lb.}} \quad \frac{1.43}{0.50 \text{ eff.}} \quad 2.86 \text{ hp., say 3-hp. motor.}$$

$$\frac{35 \times 100}{450} \quad 7.77 \text{ ft. head per 100 ft.}$$

Diagram 3 shows 160 gal. in 3-in. pipe at about 7 ft. per sec. A 3-in. main will be ample by casing up the rest of the circuit and have plenty of power in the motor to spare. This makes 2.82 or 3 gal. per min. per 100 sq. ft. for

the radiation. Using Table 15 for equalization of pipes, a 3-in. pipe is equivalent to 32 ¾-in. pipes and two 2½-in. pipes are equivalent to 36 ¾-in. pipes, so the two branch supply mains in roof and returns with basement will be 2½ in. each which will reduce the head slightly to make up for the slight excess head in the 3-in. cap using the same drop per 100 ft., in this case 7 ft., and from the gallons we can size pipes from Diagram 3 and Table 15.

Riser 1 has 7 8 gal., and as all distances are alike, they can be neglected. From Diagram 3, riser 1 is 1 in., Riser 2 requires 8.4 gal and will be 1 in. as a 1 in. gives over 9 gal. per min. for 7 ft. loss in head per 100 ft. (Diagram 3), etc. Continue as indicated.

The pump should be 2½ or 3-in. double suction with brass impeller ring bearings and water packed stuffing boxes on the pump. A 3-valve by-pass should be arranged so the water may be circulated by gravity at times. Air traps and air valves should be placed at all points necessary to relieve the air, as shown in Fig. 15.

The expansion tank (Fig. 15A) should be supplied with pop valve set at 10 lb. It should also be supplied with an automatic water feeder and swing check valve, to break any vacuum. Care must be exercised to see that the city water pressure to the automatic water feeder is sufficient to overcome the static head of 70 ft. plus the 10-lb. pop valve or a total pressure in the basement in this case of 45 lb. per sq in.

The return from the heating system forms the suction of the pump and the discharge is led into the return openings of the boiler. With down draft boilers, all connections should be tied together. It is well to make a double connection to the supply so as to reduce resistance.

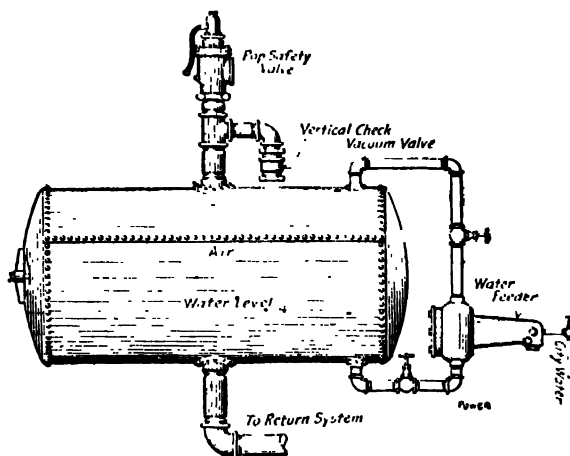


FIG. 15A.—Arrangement of expansion tank and fixtures for closed hot water heating systems operating with temperature above 210 deg. F.

14. Gravity Hot Water Heating.—The same formulas for discharge of pipes do not hold for lower velocities than 2 or 3 ft. per sec., as occur in gravity water heating. I. V. Serginsky in the *Heating and Ventilating Magazine*, November, 1913, translated and gave the formulas of Dr. R. Biel. There are two critical velocities: $V_1 = \frac{0.158}{d}$, the lower critical velocity; and $V_2 = \frac{1.382}{\sqrt{d}}$, the upper critical velocity. The proper selection of the formulas (*A*), (*B*), and (*C*) given below is made, using (*A*) for velocities below V_1, (*B*) for velocities between V_1 and V_2, and (*C*) for velocities above V_2. Both V_1 and V_2 are in feet per second and d = internal diameter of pipe in inches. h = head in inches of water at the average temperature of that in the system (for head in feet of water divide by 12).

These formulas from which Diagram 4 was constructed, are as follows:

$$h = 0.0111 \frac{LV}{d^2} \qquad (A)$$

$$h = \frac{LV^2}{d}(0.1757)\left(0.33 + \frac{0.226}{V\sqrt{d}}\right) \qquad (B)$$

$$h = \frac{LV^2}{d}(0.1757)\left(0.12 + \frac{0.226}{\sqrt{d}} + \frac{0.288}{V\sqrt{d}}\right) \qquad (C)$$

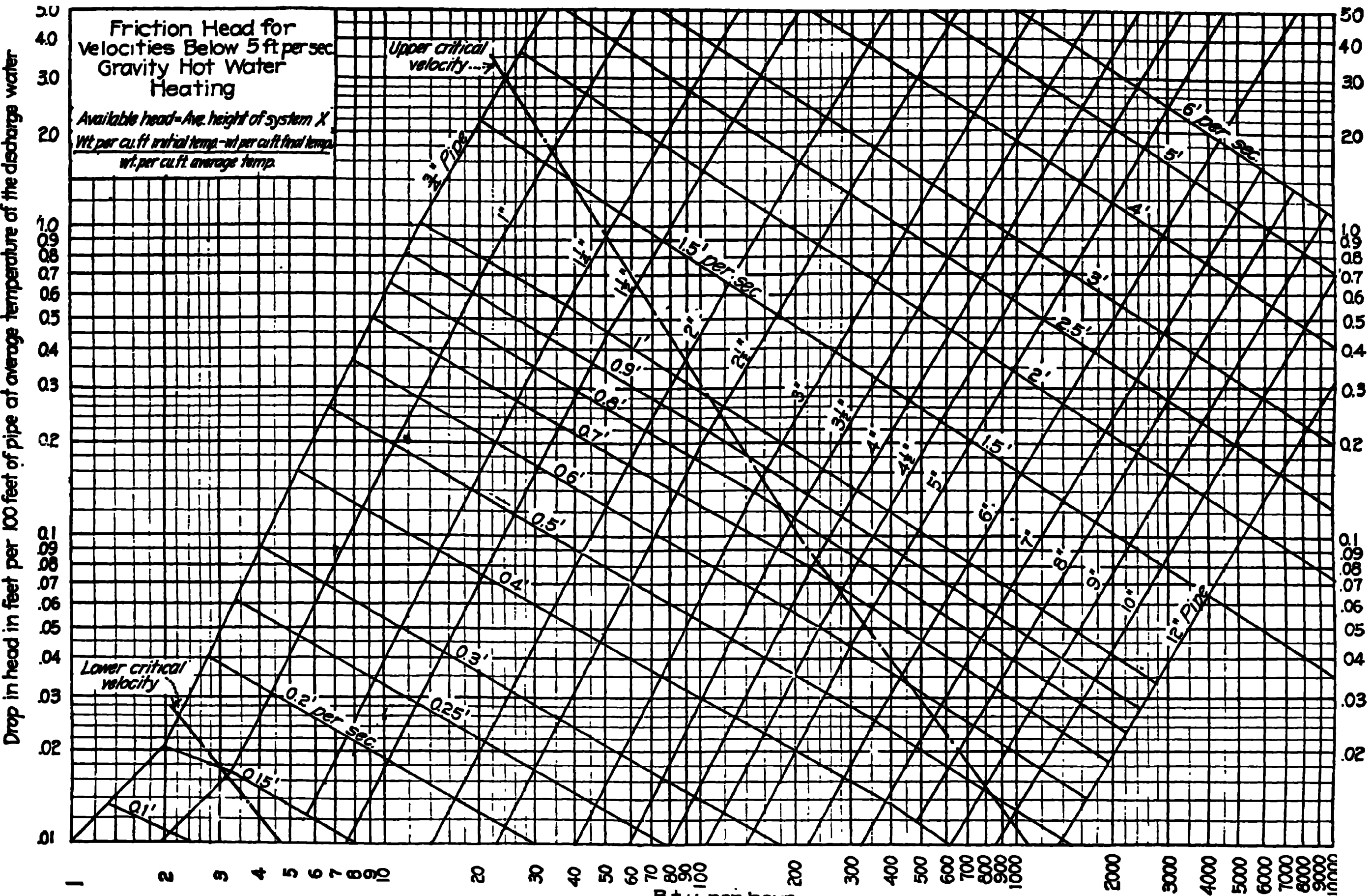

Friction Head for Velocities Below 5 ft per sec Gravity Hot Water Heating
Available head = Ave. height of system X Wt. per cu ft initial temp. – wt. per cu ft final temp. / wt. per cu ft average temp.
Upper critical velocity
Lower critical velocity
6' per sec.
1.5' per sec.
0.2' per sec.
3/4" Pipe
12" Pipe
Drop in head in feet per 100 feet of pipe at average temperature of the discharge water
Cubic feet of water = B.t.u. per hour / Average weight of water X temperature drop

Diagram 4.

As various temperatures and heights may occur in hot water heating, the writer arranged Diagram 4 to read in feet head drop per 100-ft. length of standard pipe. The discharge is in cubic feet per hour for the average weight per cubic foot. The chart is universal for any temperature condition as the feet head of water will be proportional to the weight per cubic foot. This is not true where specific conditions of temperature are named.

The total head available for gravity heating is the difference in weights per cubic foot at the final and initial water temperatures divided by the weight per cubic foot at the average temperature multiplied by the average height of the system. To determine the cubic feet per hour, divide the heat loss multiplied by 125% by the product of the assumed temperature drop by the weight per cubic foot at the average water temperature. The result will be the cubic discharge for the whole system. Using Diagram 4, the main may be directly determined. For other circuits, divide the total cubic feet by the total square feet of radiation and determine the size for subsidiary circuits in the same manner. If mains are laid out so radiators are equidistant from the boiler, the rest of the sizes can be read from equalization Table 15 in proportion to the square feet of heating surface installed. This applies to all gravity hot water heating plants of all descriptions.

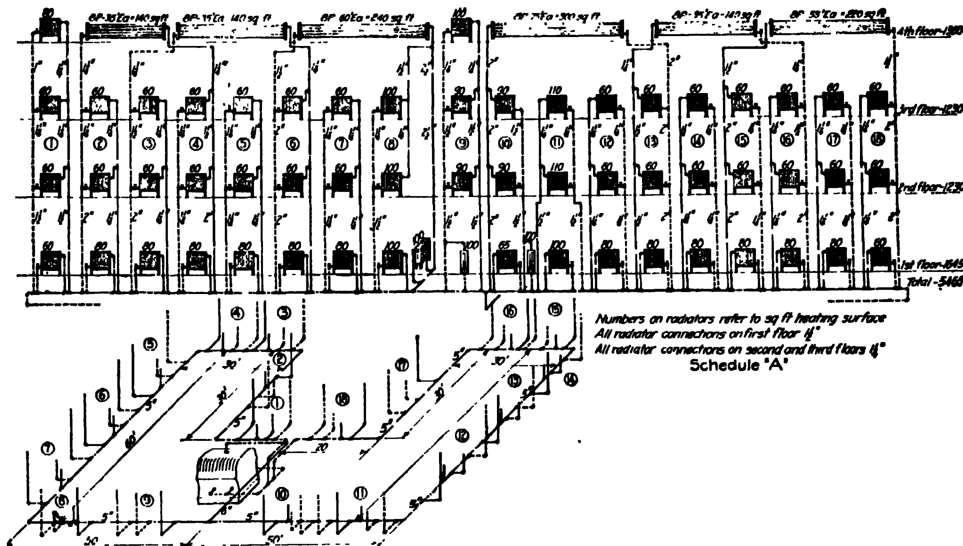


FIG. 16.—Gravity hot water heating system layout, 210 deg. average temperature, 30 deg. drop, shunt system, single main in basement.

Table 15 is an equalization table based on the friction formula, p. 1106, used for Diagram 3. Tests give higher values for the smaller size pipes, so there is a safeguard of about 10% where the larger size pipes are in terms of the smaller. The light face figures are the number of pipes of equivalent area; the heavy face figures, the number with the same drop in friction head for the same discharge per unit of time. The heavy lines drawn diagonally and figures on the margin give the ratio on area increase for the number of smaller pipes and also the ratio of the decrease in velocity.

All water systems with a temperature over 180 deg. maximum should be closed systems with a pop valve set at least 5 lb. above the pressure corresponding to the maximum temperature, *i.e.*, 220 deg. requires a 10-lb. pop valve. All water systems below 180 deg. maximum temperature may be open systems, but it will be found that all hot water systems circulate better under some pressure.

Objection has been made to closed water systems as being dangerous due to likelihood of explosion. This is erroneous provided proper safety valves are used. There is just as much danger of blowing all the water out of the open system and cracking the cast-iron boiler if cold water enters, as there is from a possible rupture from a water temperature of 220 deg. with a proper safety valve. *Safety valves on all heating systems should be proportioned to the grate area of the boiler as this is the source of the maximum available energy.*

14a. Illustrative Problem.—*Closed Gravity Hot Water System.*—Fig. 16 is a layout for a gravity hot water system for the same problem as Fig. 15 with the main below, all risers shunted, and coils on the fourth floor. Water is taken at 210 deg. average temperature with 30-deg. drop. This will have to be a closed system with the expansion tank of the same type as the forced hot water system (Figs. 15 and 15A). This will give a maximum temperature in the system of 225 deg. or the same as 5-lb. steam, and requires a 10-lb. pop valve on the expansion tank.

Heat loss plus 25% as before = 1,540,000 B.t.u. (Table 13)

Average height of system—schedule "A," Table 13.

$$\begin{aligned} &\text{4th fl. } 1360 \times 55 = 74{,}800 \\ &\text{3rd fl. } 1230 \times 40 = 49{,}200 \\ &\text{2nd fl. } 1230 \times 20 = 24{,}600 \\ &\text{1st fl. } \frac{1645}{5465} \times 8 = \frac{13{,}160}{161{,}760} \end{aligned}$$

$$\text{Average height} = \frac{161{,}760}{5465} = 29.6 \text{ ft., say 30 ft.}$$

Heating surface = 5465 sq. ft. Schedule *A*, Table 13.

Length of main = 300 ft. on basement ceiling.

From Table 2, p. 1145, column (6), W at 210 deg. F. average temperature = 59.88 lb., at 225 deg. F. = 59.5 lb., and at 195 deg. F. = 60.24 lb.

$$\frac{1{,}540{,}000}{30 \times 59.88} = 860 \text{ cu. ft. per hr.}$$

$$\frac{100 \times 860}{5465} = 15.73 \text{ cu. ft. per hr. per 100 sq. ft. of surface.}$$

$$\text{Head} = \frac{60.24 - 59.5}{59.88} \times 30 \text{ ft.} = 0.371 \text{ ft. of water.}$$

$$\frac{0.371 \times 100}{300} = 0.1236 \text{ ft. drop per 100 ft. of main; the size of one pipe necessary is 6 in.}$$

From Diagram 4, with a drop of 0.1236 ft. per 100 ft. and a discharge of 862 cu. ft. per hr., this figures a 6-in. main because the distance is shorter and the drop is greater than in Fig. 17.

Each of the two branch mains should be (from Table 15) two 5 in. as 1.62 of 5-in. mains equal one 6-in. main.

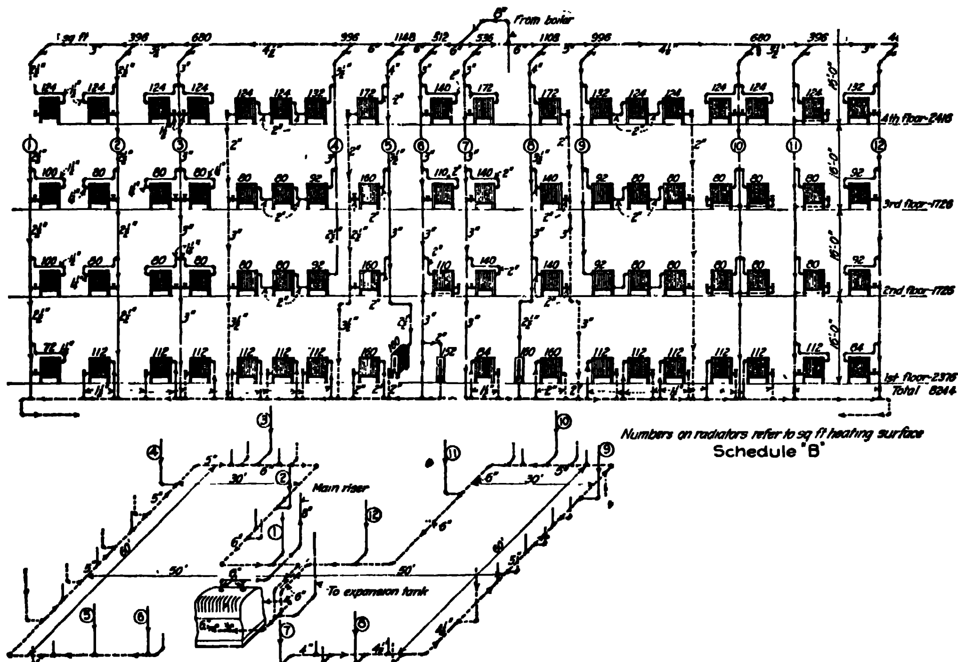


FIG. 17.—Overhead gravity hot water open tank system layout, 170 deg. average temperature, 25 deg drop.

In this system each riser and radiator is connected directly off the main and the power of circulation is derived from the cooling of the radiators. The connection practically increases the size of the main. The head will have to be decreased through the risers and radiators as the temperature falls along the line; there will be only a small part of the drop in temperature through any radiator. We have for the main 0.1277 ft. drop per 100-ft. and a 6-in. dividing into two 5-in. branches. In this method there are no reducing fittings and every temperature increment is added and none are minus so the velocity will be greater with less friction from fittings reducing on the run. One 6-in. main is equivalent to 193 ¾-in. pipes (see Table 15). With 5500 ft. surface take 1⅛ times for the first floor, 1 for the second and third, and ¾ for the fourth floor.

For first floor:

$\frac{193 \times 1.5}{5500} = 0.0527$ ¾-in. pipes per sq. ft. of radiation = 5.27 ¾-in. pipes per 100 sq. ft. or from Table 15, equivalent to a 1½-in. pipe per 100 sq. ft. of radiation.

For second and third floors:

$\frac{193 \times 1}{5500} = 0.0351$ ¾-in. pipes per sq. ft. of radiation = 3.51 ¾-in. pipes per 100 sq. ft. or, from Table 15, equivalent to 1¼-in. pipe per 100 sq. ft. of radiation.

For fourth floor:

$\frac{193 \times 0.75}{5500} = 0.0263$ ¾-in. pipes per sq. ft. of radiation = 2.63 ¾-in. pipes per 100 sq. ft. or, from Table 15, equivalent to a 1¼-in. pipe per 100 sq. ft. of radiation. From the above and the sketch, the pipe sizes may be easily calculated.

Gravity Hot Water Open-tank System (Fig. 17).—Gravity hot water overhead system 170 deg. F. average temperature water—25 deg. drop. Heat loss as before plus 25% = 1,540,000 B.t.u. (Table 13).

Heating surface = 8244 sq. ft.
Total length circuit = 450 ft.
Outboard temperature water = 183 deg.: W = 60.52
Return temperature water = 158 deg.: W = 61.04
W at 170 deg. F. av. temp. = 60.8 (Table 2, Column 6)
Average height of system:

4th floor 2416 × 55 = 132,900
3rd floor 1726 × 40 = 69,000
2nd floor 1726 × 20 = 34,500
1st floor 2376 × 8 = 19,000
Total 8244 sq. ft. = 255,400

$$\text{Average height} = \frac{255{,}400}{8244} = 31 \text{ ft.}$$

Cubic feet per hour per square feet

$$\frac{1{,}540{,}000}{25 \times 60.8} = 1015 \text{ cu. ft. per hr.}$$

$$\frac{100 \times 1015}{8250} = 12.3 \text{ cu. ft. per hr. per 100 sq. ft. of surface.}$$

$$\text{Head} = \frac{61.04 - 60.52}{60.8} \times 31 \text{ ft.} = 0.265 \text{ ft. of water.}$$

$$\frac{0.265 \times 100}{450} = 0.0588 \text{ ft. drop per 100 ft. of main.}$$

From Diagram 4 with a drop of 0.0588 ft. per 100 ft. and a discharge of 1015 cu. ft. per hr., the size of one pipe necessary is 8 in.

From Table 15 an 8-in. main is equivalent to 397.7 of ¾-in. pipes.

$$\frac{397.7 \times 100}{8250} = 4.82 \text{ of ¾-in. pipes per 100 sq. ft. of radiation.}$$

As every radiator is equidistant from the boiler, in using Table 15 we have 4.82 of ¾-in. pipes for each 100 sq. ft. of surface. By following the diagram and adding up the number of ¾-in. pipes necessary for the required radiation in the branch, the nearest size can be found from Table 15. The square feet of radiation are indicated at the top of each riser. Riser 3 has 680 sq. ft. surface. $\frac{680 \times 4.82}{100}$ 32.6 of ¾-in. pipes. From Table 15 these are equivalent to one 3-in. pipe. Riser 4 has 996 sq. ft. surface. $\frac{998 \times 4.82}{100} = 48$ of ¾-in. pipes. From Table 15 these are equivalent to one 3½-in. pipe. Where a size is a little small in one circuit, make the next a little larger. These pipes may also be sized in the same manner as for forced hot water heating by assuming the same drop per 100 ft. and the cubic feet of water per 100 sq. ft. of surface, or the quantity 0.0588 ft. per 100 ft. and 12.3 cu. ft. per 100 sq. ft. per hour, using Diagram 4.

The expansion tanks should be set at least 5 ft. above overhead main and connected to the return of boiler by a 1½-in. pipe. There is a total of about 9000 sq. ft. and with a factor of 1.5 pints per sq. ft., $\frac{1.5 \times 9000}{8} = \frac{13{,}500}{8} =$ 1700 gal. in the system, or $\frac{1700}{7.5} = 230$ cu. ft. Assuming the water cold at 70 deg. F., and that 230 deg. F. is the maximum temperature, the percentage expansion of the water in the system is $\frac{62.3 - 59.37}{62.3} = \frac{2.93}{62.3} = 4.7\%$ 4.7% of 230 cu. ft. = 10.8 cu. ft. = 81 gal. A 100-gal. tank will be large enough.

15. Hot-air Furnace System.—The hot-air system, commonly known as the gravity warm-air heating system, consists essentially of a furnace with casing and smoke pipe, together with a properly designed system of heating pipes (leaders), outlets (registers), and cold-air ducts to convey the unheated air to the furnace.

It is recommended that the Standard Code Regulating the Installation of Gravity Warm-Air Heating Systems in Residences (latest edition) be followed when installing gravity warm-air heating plants in residences.

***15a.* Furnaces.**—Hot air furnaces are best adapted for heating dwellings under 2000 sq. ft. ground area, and small churches or auditoriums where intermittent operation is largely the practice. Small plants may be installed for lower first cost than for other types of systems. The specific heat and carrying capacity of air as a heating medium limit the economical use of furnaces for large plants, increasing the fire risk and cost of both operation and installation. Their action is responsive and quick due to the comparatively small weight of the apparatus and medium, making an ideal system for intermittent operation under these conditions.

The fuel rate is high for all hot air systems in zero weather, but due to the wide range of carrying capacity and temperature of air as a medium to meet outside weather conditions, hot air systems give an economical overall fuel rate for the entire season. The furnace should not have a greater capacity in square feet of heating surface than that for which the flue is designed, or incomplete combustion due to low flue temperature will occur. The height of flue is more important than grate area. A draft of 0.16 to 0.2 in. of water should be available, especially for soft coal. Where the chimney is of minimum height, the furnace should have little flue travel; where the height is available, longer flue travel is permissible. A cool smoke pipe is no sign of economy and usually means incomplete combustion.

Of late, various types of oil burners and gas burners have been used in connection with warm-air furnaces. In general, the efficient use of a gas burner requires a specially designed fire box.

The hot-air furnace consists of a cast-iron grate and fire pot in which the fuel is burned, a cast-iron combustion dome with the fire door, and a cast-iron or sheet metal radiator through which the gases pass to the chimney. The whole is encased in galvanized iron, sometimes with a double casing with air space for insulation. The area of diameter of the grate, always given in catalogues, and the height of the chimney determine the fuel capacity, the total coal consumed per hour, and the rate per square foot of grate. This is primarily the limiting capacity of any furnace no matter how much cooling surface may be between the grate and flue. The average furnace secures from 5000 to 6000 heat units per lb. in combustion of soft coal and from 7000 to 8000 heat units per lb. in combustion of hard coal. The average fuel rate per hour per square foot of grate for the winter is about 4 lb. It may be as high as 8 lb. (with low outside temperatures and good draft) and as low as 2 to 2½ lb.

The cast-iron fire pots are ribbed or slotted for use with soft coal in order to provide ample air supply for the combustion of the volatile products distilled from the fuel bed. They are often build in two pieces, one of which may be replaced with a gas ring in order to burn gas and coal in conjunction. The fire pot is the first part of the furnace to be replaced. If the casting is too heavy, the radiating qualities are reduced, and if it is too light, it is liable to warp from the heat. All fire pots deteriorate with time and use due to slow oxidation of the iron, and for good economy they should be replaced every 3 or 4 yr. If the sides of the fire pot are nearly perpendicular, the ashes are less likely to collect on the sloping sides and interfere with the proper combustion of fuel.

The radiator is the heating surface forming the passage for the gases to the chimney. In some cases this is set directly on the fire pot and combined with the combustion dome. Cast radiators should be constructed so as to insure against gas leakage in the use of soft coal by having as few joints as possible. The cast-iron radiator has fewer joints than a steel radiator and is practically immune from corrosion, but the heating surface is more limited than that of the sheet metal type. The great trouble with all hot air furnaces is the deterioration of the joints and the nuisance of coal gas leakage into the rooms. These joints are made with a cup or groove and tongue packed with an asbestos cement. As far as joints are concerned, if the furnace is taken down, cleaned, and the joints remade about every 4 years, there will be little trouble from this cause with any of the types. The average furnace contains 18 to 22 sq. ft. of heating surface per square foot of grate, and the better class contains 10 to 30 sq. ft. per sq ft. of grate. This quantity is seldom, if ever, given in catalogues.

Some furnace manufacturers have discarded the use of the radiator and use an extra large combustion chamber. This is advantageous with a low chimney because the travel of the gases and the frictional resistance are reduced. The use of the radiator gives long flue travel and is advantageous with high chimneys where greater pressure is available.

Furnaces are sometimes encased in brick but generally with galvanized iron, and in the better class of furnace, with a double galvanized-iron casing with 1-in. air space for insulation. Brick settings are large and undesirable. A plenum chamber is generally formed in such manner that the cross radiation from the high temperature heating surfaces interferes with the flow of warm air, resulting in low velocities. Such is not the case with galvanized-iron casings which are smooth and in better proportion with the required area. Brick settings, however, are more durable. All sudden changes in areas and velocities, where the flow of fluids is involved, cause loss of head or resistance to flow.

The cold air connection is generally taken from the outside with an overhead or a flue under ground leading into the base of the furnace. A return flue should be taken from the floor above, preferably in a hall, and fitted with a damper so recirculation may be established at will for extreme weather due to the high peak load and excessive fuel requirements. The velocity and power of the flues is increased by the use of out door air. The cold air flue should have 75% of the combined area of the hot air flues. Fans may be used in connection with furnace heating either to recirculate the air or to take it from out of doors.

15b. Flues and Hot-air Pipes.—Hot air pipes (leaders) are round except when passing up stud partitions. They are made of IX tin or 26 galvanized iron and should be graded up in the direction of floor 1 in. in 10 ft. Where leads from the furnace are over 15 ft., add 1 in. to diameter for each additional 10 ft. No horizontal lead should be less than 8-in. pipe diameter. When pipes are 14 in. and over, they should be connected to the furnace bonnet with twin connections and Y branch. Where long runs occur or where the pipes are in an outside wall double pipe is used. Also if double pipe is used in round section for long smoke flues, it will help the draft. There is no economy in a cold smoke pipe. It would mean that a hard fire would have to be operated simply to keep up proper combustion and flue temperature.

If the furnace has a single casing, it should be covered with a layer of paper or corrugated pipe covering wired on. The horizontal air piping, especially the long runs, should be wrapped in the same manner. There will be a large saving in fuel and efficiency, and a warm cellar will be avoided if piping and furnace are insulated. All stacks should run in inside walls and an inside chimney will help the draft to a greater extent than one outside the building.

Registers are known as wall, floor, base, flat, and convex. Floor registers require a tin or galvanized register box. Convex registers are those whose lattice extends beyond the wall face in order to give a greater percentage of free area. It is not safe to calculate on more than 50% clear area for register. Table 17 gives the capacity of most common sizes.

Provision should be made to remove a certain portion of the air from the building, although in most residences the construction permits considerable air change. Fireplaces make excellent outlets for the removal of air.

TABLE 17.—CAPACITIES AND DIMENSIONS OF WARM AIR PIPING AND REGISTERS

Diameter of round cellar or riser pipe (inches)	Rectangular riser pipe (inches)	Area of riser pipe (sq. in.)	Required free area register face (sq. in.)	Size of round register (diameter in inches)	Size of wall register (inches)	Size of floor register (inches)
6	3 × 9½	28	52	10	8 × 8	8 × 8
6½	3½ × 9½	33	62			
7	3½ × 11	38	72	10	8 × 10	8 × 10
7½	3½ × 12½	44	84			
8	3½ × 14	50	96	12	8 × 12	8 × 12
8½	4 × 14	57	108			
9	4 × 16	64	120	14	10 × 12	10 × 12
9½	4 × 18	71	134			
10	4 × 20	78	142	14	12 × 12	10 × 16
10½	6 × 14½	86	158			
11	6 × 16	95	176	16	12 × 15	12 × 15
11½	6 × 17½	104	194			
12	6 × 19	113	201	18	14 × 15	12 × 20
12½	6 × 20½	122	222			
13	6 × 22	132	242	18	14 × 18	14 × 18
13½	8 × 18	143	254			
14	8 × 19	154	276	20	16 × 18	14 × 22
14½	8 × 20½	165	298			
15	8 × 22	176	320	24	16 × 20	16 × 20
16	8 × 25	201	358	24	18 × 20	16 × 24
18	10 × 25½	254	450	24	20 × 24	18 × 27
20	12 × 26	314	554	28	22 × 26	20 × 30
22	14 × 27	380	686	30	24 × 30	24 × 30
23	14 × 29½	415	707	30	27 × 27	24 × 32
24	14 × 32	452	770	30	28 × 28	24 × 36

15c. Designing Data for Hot-air System.—Table 18 gives the capacities in cubic feet of space heated by hot-air furnaces and total cross section of the furnace pipes that may be

supplied. The area between the casing proper and radiator should be 120% of the area of the pipes supplied. These capacities are based on: (1) 8 lb. of fuel per sq. ft. of grate, which rate may be easily obtained in zero weather with a good flue; (2) the initial temperature with all outside air at −10 deg. F., 0 deg. F., and +10 deg. F., (3) air heated to 180 deg. and entering the room at 150 deg.; and (4) 70 deg. room temperature.

Table 18.—Capacities of Warm Air Furnaces of Ordinary Construction in Cu. Ft. of Space Heated

Divided space, Entering air at + 10° F.	Divided space, Entering air at 0° F.	Divided space, Entering air at − 10° F.	Undivided space, Entering air at + 10° F.	Undivided space, Entering air at 0° F.	Undivided space, Entering air at − 10° F.	Fire pot, Dia. (in.)	Fire pot, Area (sq. ft.)	Fire pot, Dia. of casing (in.)	Total cross section of pipes (sq. in.)	Diameter of single pipe (in.)	No. of 8-in. pipes	No. of 9-in. pipes	No. of 10-in. pipes	No. of 12-in. pipes
12,000	10,000	8,000	17,000	14,000	12,000	18	1.8	30–32	180	15	4.8	3.6	2.8	1.8
14,000	12,000	10,000	22,000	17,000	14,000	20	2.2	34–36	280	19	8.8	6.5	5.0	3.2
17,000	14,000	12,000	26,000	22,000	17,000	22	2.6	36–40	360	21	10.0	8.4	6.3	4.1
22,000	18,000	14,000	30,000	26,000	22,000	24	3.1	40–44	470	24	16.0	12.0	8.9	5.7
26,000	22,000	18,000	35,000	30,000	26,000	26	3.7	44–50	565	27	21.0	15.0	12.0	7.5
30,000	26,000	22,000	40,000	35,000	30,000	28	4.3	48–56	650	29	25.0	19.0	14.0	9.1
35,000	30,000	26,000	50,000	40,000	35,000	30	4.9	52–60	750	31	30.0	22.0	17.0	10.0

The capacity of a furnace in cubic feet of space heated is not sufficiently accurate due to the variation in requirements. The total area of heat pipes in square inches is definite when the B.t.u. losses and pipe sizes are determined.

Let H = total heat units per hour required for the air to be raised from 0 to 180 deg.
h = B.t.u. loss determined by glass and wall.
a = total area of pipes, in square inches.
A = square feet grate area.
d = density of air at 165 deg. F. = 0.0635 lb. per cu. ft. (Table 3, col. 3).

Velocity in the casing = 5 ft. per sec.
Area of the casing in square inches = $1.2 \times a$.
Specific heat of air = 0.24 B.t.u. per lb.

$$H = \frac{3600 \text{ sec.} \times 5 \text{ ft.} \times 1.2''a'' \times (180 - 0) \times 0.24 \times 0.0635}{144}$$
$$= (411 \times a) \text{ B.t.u. per hr.}$$

All hot-air furnace ratings are based on air entering at 0 deg. F. and raised to 180 deg. F. and with a temperature entering the room at 150 deg. F. in zero weather with the room at 70 deg. F. In case a greater air supply is desirable for ventilation, the entering temperature may be reduced, as explained under fan heating. If the air enters at 0 deg F. and is heated to 180 deg. F. and the diffusion is 150 deg. F. −70 deg. F. = 80 deg. F.

$$H = \frac{(180 \text{ deg.} - 0 \text{ deg.}) \times h}{(150 \text{ deg.} - 70 \text{ deg.})} = 2.25h \text{ or B.t.u. loss.}$$

If the air is recirculated or raised from 70 deg. instead of 0 deg.,

$$H = \frac{(180 \text{ deg.} - 70 \text{ deg.}) \times h}{(150 \text{ deg.} - 70 \text{ deg.})} = 1.375h, \text{ or a little over}$$

½ the former amount.

If the furnace uses 7500 B.t.u. per lb., of the 12,000 B.t.u. per lb. available from the fuel, it is $\frac{7500}{12{,}000} = 65\%$ efficient.

For air entering at 0 deg. F., the coal consumed per hour in terms of B.t.u. loss is $\frac{2.25}{7500}h = 0.0003h$ (pounds). For air entering at 70 deg. F. the coal consumed per hour in pounds is $\frac{1.375}{7500}h = 0.000183h$. If 8 lb. of coal are burned per square foot of grate area per hour in extreme weather, the grate area in terms of B.t.u. loss is $\frac{0.0003h}{8} = 0.0000375h$ sq. ft. for air entering at 0 deg. F., and $\frac{0.000183h}{8} = 0.0000229h$ sq. ft. for air entering at 70 deg. F.

If the total heat losses plus 25% for a building are say 120,000 B.t.u. per hr. for air entering at 0 deg. F., the coal burned is $120{,}000 \times 0.0003 = 36$ lb. per hr. and the grate area is $120{,}000 \times 0.0000375 = 4.5$ sq. ft.; for air

entering at 70 deg. F., the coal burned is 120,000 × 0.000183 = 22 lb. per hr. and the grate area is 120,000 × 0.0000-229 = 2.75 sq. ft.

Table 19, by R. C. Carpenter, gives the velocities per square foot of flue with 50% allowed for friction. The difference in temperature between the outside air and that in the flue, together with the height, determines the velocity. The cubic feet of air required per minute at 165 deg. F. average, with a density of 0.0635 lb. per cu. ft., a specific heat of 0.24, and a diffusion temperature of 80 deg F. will be in terms of the B.t.u. loss, h.

$$\frac{h}{60 \text{ min.} \times 0.0635 \times 0.24 \times 80°} = 0.0137h \text{ cu. ft. per min.}$$

From Table 19 and 150 deg. difference between flue and outside, we have for first, second, and third floors.

First floor	5 ft. height	298 ft. per min.
Second floor	10 ft. height	419 ft. per min.
Third floor	20 ft. height	593 ft. per min.

The flue areas will be

$$\text{First floor } \frac{0.0137h \times 144}{298} = 0.0137h \times 0.483 = 0.0066h \text{ sq. in.}$$

$$\text{Second floor } \frac{0.0137h \times 144}{419} = 0.0137h \times 0.344 = 0.0047h \text{ sq. in.}$$

$$\text{Third floor } \frac{0.0137h \times 144}{359} = 0.0137h \times 0.243 = 0.0033h \text{ sq.in.}$$

15*d*. Rules Governing Hot-air Furnaces.—1. An offset in the riser pipe is equivalent to an addition to the length of the cellar pipe and should be counted in when measuring the total length of pipe.

2. When the warm air pipes are taken from the top of the bonnet of the heater, the tops of all elbows should be on a level so the flow will be equal.

3. An air space should be left around all pipes passing through masonry walls so that the pipe will not be chilled.

4. All pipes should have dampers close to the furnace.

5. When heating rooms on the cold side of the house or a room with a large amount of glass, place one register in the floor as near as possible to the furnace and a cold air register face in the floor under or near the window and connect with a separate pipe to bottom of casing, thereby removing cold air from room and inducing a flow of warm air.

TABLE 19.—QUANTITY OF AIR DISCHARGED IN CUBIC FEET PER MINUTE THROUGH A FLUE 1 SQ. FT. IN SECTIONAL AREA

External temperature of air 32 deg.—Friction 50%. (By R. C. Carpenter)

Height of flue (ft.)	Excess of temperature of air in flue above external air								
	5 deg.	10 deg.	15 deg.	20 deg.	25 deg.	30 deg.	50 deg.	100 deg.	150 deg.
1	24	34	42	48	54	59	76	108	133
5	55	76	94	109	121	134	167	242	298
10	77	108	133	153	171	188	242	342	419
15	94	133	162	188	210	230	297	419	514
20	108	153	188	217	242	265	342	484	593
25	121	171	210	242	271	297	383	541	663
30	133	188	230	265	297	325	419	593	726
35	143	203	248	286	320	351	453	640	784
40	153	217	265	306	342	375	484	684	838
45	162	230	282	325	363	398	514	724	889
50	171	242	297	342	383	419	541	765	937
60	188	264	325	373	420	461	594	835	1006
70	203	286	351	405	465	497	643	900	1115
80	217	306	375	453	485	530	688	965	1185
90	220	324	398	460	516	564	727	1027	1225
100	243	342	420	485	534	594	768	1080	1325
125	273	383	458	542	604	662	855	1210	1480
150	298	420	515	596	665	730	942	1330	1630

6. Always take the cold air supply from the coldest side of the house—west, northwest, or north.

7. Cold-air box should be ⅘ the total area of the warm-air pipes. When recirculating air it should be equal to area of the warm air pipes.

8. A cold-air pit under the heater should never be more than 14 in. deep; a pier in the center is desirable to support the ash pit. With more than one air opening, place a partition across.

9. Where there is a long run for the smoke connection, the smoke pipe should be covered and allowance made in the chimney height, or the flue gases will be chilled, reducing draft pressure and interfering seriously with the operation of the plant. The chimney should be, if possible, inside the building instead of outside. Where long runs of smoke pipe occur, use double pipe with an air space.

16. Indirect Heating System.—The indirect heating system is a combination system in which steam or hot water is employed to heat pipe coils or radiators over which air is circulated or blown and transmitted through ducts to the various rooms of a building. There are two methods of producing circulation, one by gravity and one with blowers. Gravity indirect systems are so uncertain that, except for house heating purposes, they are becoming obsolete. On the other hand, electric current is so easy of access and low priced, that when hot air heating is desired, it is far more satisfactory and the operation is more certain if a fan and motor are used to force the air through the coils and ducts. The cost of the system is thereby largely reduced and less space is required.

Indirect radiators are built of pipes or cast-iron sections, and in stacks for heating individual flues. Except when very high pressure steam is required, the use of "Vento" cast-iron radiators is superseding the use of pipe coils to a greater and greater extent. Both the size of a pipe coil stack and the number of sections in a cast-iron indirect radiator depend upon the volume of air to be passed through it. Stacks are arranged in series, in parallel, or in series-parallel, all depending on the desired increase in air temperature, the volume of air to be heated. and the pattern of the radiator itself.

If the volume of air be heated is small, as in house heating, the problem of designing and selecting indirect radiators is simplified, for often one radiator, one stack deep, is sufficient to take care of the volume of air. Fig. 18 shows a typical cast-iron indirect radiator arranged to take air from out of doors and discharge it by gravity through a flue into a room. These radiators are sometimes arranged so that all or part of the air is passed through or by-passed around the stack, with two dampers working in conjunction in such a manner that the air may be tempered and mixed at will. The dampers may be operated by hand or with a thermostat.

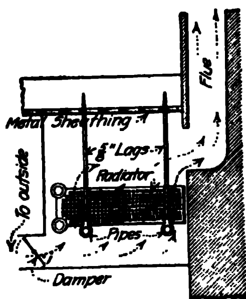


Fig. 18.—Indirect heating stack and hot air flue for steam or water.

If the volume of air to be heated is large, the problem is somewhat more involved, due to the large number of variables. All indirect heating problems, however, are solved in about the same general manner, whether the volume of delivered air is large or small. If the volume is large, the radiators may either be made larger or a number of them may be placed in parallel, or both, to increase the area through which the air passes, known as the free area. If the outside temperature is low, the amount of heating surface per square foot of free area must be increased, either by placing the stacks in series, or by selecting one stack whose particular design gives the necessary amount of heating surface per square foot of free area.

The amount of heat to be delivered in the air in the rooms is the product of the volume, the rise in temperature, and the specific heat of the air, but since the volume and temperature rise depend on the square feet of heating surface per square foot of free area, $\frac{Ns}{A} = f$, and the velocity of the air, the heat to be delivered also depends on the rates, $\frac{Ns}{A} = f$, and the velocity of the air, N being the number of stacks in series. If a velocity is assumed, and the temperature range, temperature conditions, and volume of air are known, the value of f for those conditions may be computed from equation 6 or 7, Art. 16*b*, and a stack of a certain pattern or a number of stacks in series of a certain pattern may be selected from Table 20. (See Art. 16*a* for method of computing the volume of air necessary.) After the pattern of stack and the number of stacks in series are selected, it is necessary from the volume and the velocity to compute the free area from $A = \frac{Q}{V}$. Following this, with values of the free area A, and the ratio f (Table 20), the total heating surface may be computed from $Ns = Af$. The value of Ns thus computed should agree with the value of S computed from $S = \frac{\text{B.t.u. per hr. required}}{(\theta_s - \theta_m) \times K}$. The

TABLE 20.—DATA ON TYPES OF CAST-IRON INDIRECT RADIATORS

Pattern	Length (in.)	Height (in.)	Heating surface per section (sq. ft.) S	Width of each radiator in stack (in.)	Spacing c. to c. (in.)	Net free area (sq. ft. per section) A	Sq. ft. surface per sq. net area (f') $f' = \frac{S}{A}$	Friction (lb. per sq. ft. per 150-ft. velocity per min. 1 stack deep)
Perfection Pin	36¼	10	10.0	2¾	2¾	0.1965	50.9	0.0187
	36¼	10	10.0	2¾	2⅞	0.225	44.4	0.0166
	36¼	14	15.0	2¾	2¾	0.1965	76.34	0.0270
	36¼	14	15.0	2¾	2⅞	0.225	66.66	0.0230
	36	14	12.0	3⅝	3⅞	0.355	33.8	0.154
Excelsior standard	36	8	12.0	3⅝	3⅝	0.296	40.54	0.013
Sanitary school pin	36⅛	15¼	20.0	4	4	0.45	44.4	0.0134
			20.0	4	4 3/16	0.494	40.5	0.0123
Sterling	36¾	15¾	20.0	3½	3½	0.3	66.6	0.0203
Cardinal	37¼	11¼	15.0	3½	3½	0.278	54.0	0.01574
Narrow Vento	40		7.5		4⅝	0.525	14.28	0.00616
	40	41	7.5	3½	5	0.62	12.10	0.00575
6¾ in. wide	40		7.5		5⅜	0.729	10.29	0 00522
	50		9.5		4⅝	0.65	14.61	0.00616
	50	51	9.5	3½	5	0 768	12.37	0.00575
	50		9.5		5⅜	0.905	10.5	0.00522
	60		11.0		4⅝	0.781	14.1	0.00616
	60	60¾	11.0	3½	5	0.921	11.94	0.00575
	60		11.0		5⅜	1.085	10.14	0.00522
Regular section Vento	30		8.0		4	0.225	35.6	0.0133
	30	30	8.0	3½	4⅝	0.390	20.5	0.0077
	30		8.0		5	0 46	17.4	0.00726
	30		8.0		5⅜	0.542	14.76	0.00638
9⅛ in. wide	40		10.75		4	0 35	30.71	0.0115
	40	41	10.75	3½	4⅝	0.525	20.48	0.0077
	40		10.75		5	0 62	17.34	0.00726
	40		10.75		5⅜	0.729	14.75	0.00638
	50		13.5		4⅝	0.65	20.77	0.0077
	50	50 29/32	13.5	3½	5	0.768	17.58	0.00726
	50		13.5		5⅜	0.905	14.92	0.00638
	60	60¾	16 0	3½	4⅝	0 781	20.5	0.0077
	60		16.0		5	0.921	17.38	0.00726
	60		16.0		5⅜	1.085	14.75	0.00638
	72		19.0		4⅝	0.937	20.28	0.0077
	72	72	19.0	3½	5	1.104	17.21	0.00726
	72		19 0		5⅜	1.303	14.58	0.00638

For friction in lb. per sq. ft. for any velocity, divide by 150, square the result, and multiply by quantity in last column. For inches of water, multiply this result by 0.1925.

Multiply by number of stacks deep for total friction.

transmission factor K is defined in Art. 16b. $(\theta_s - \theta_m)$ is the mean temperature difference between the steam and air and is computed from Eq. 3, Art. 16b.

With the total heating surface, the heating surface per section, and the number of stacks in series, the total number of sections and the number of sections per stack may be computed. (See illustrative problem in Art. 16c.)

Where the radiators are in series, and N is used to denote the number of stacks, it is easily seen that the heating surface is increased while the free area remains constant, thus increasing the value of f. In such a case, $f = \frac{Ns}{A}$. Where one stack deep only is used, this reduces to $f = \frac{s}{A} = \frac{S}{A}$. The above considerations assume that all the radiators are in series. Practically, where the volume is so great that a radiator is too long if it is built up of enough sections to satisfy the heating demand, it may be cut in two or more pieces making two or more radiators in parallel; in other words, two or more stacks in parallel. In that case, $N = 1$ the same as before, N only referring to the number of stacks deep or the number of stacks in series. The quantity s is the surface of all the radiators in any one row in parallel.

16a. Ventilation with Indirect Heating.—Care should be taken in assuming a temperature at which the air is to enter. The best temperature to assume depends on the desired number of air changes in the room per hour and varies between being too cool to be effective and too hot for comfort. The number of air changes per hour, neglecting infiltration, is the volume of air necessary to furnish the B.t.u. losses divided by the cubic contents of the room. If, by trial, certain temperature assumptions give too great or too little air change, new assumptions will have to be made before starting the design of appropriate stacks.

Since the air leaves the room through foul air ducts at room temperature and is discharged into the atmosphere, which is often much below zero, it is easy to see that more heat must be furnished by the indirect radiators than is necessary to supply the heat losses; in fact, the exact amount to be furnished is that lost in the ducts, that used to supply the room losses, and that which is lost to the outside atmosphere through the vents. For example, if the outside atmosphere were at −10 deg. F., the air leaving the radiator at 125 deg. F., the temperature drop in the ducts at 5 deg. F., the temperature of the air entering the room at 120 deg. F., and the room temperature 70 deg. F., the ratio of total heat to the useful heat is the same as the ratio of the temperature differences; thus, using the above temperature assumptions,

$$\frac{\text{Total heat}}{\text{Useful heat}} = \frac{(125 \text{ deg.} - -10 \text{ deg.})}{(120 \text{ deg.} - 70 \text{ deg.})} = \frac{135}{50}$$

or

$$\text{total heat required} = \frac{\text{B.t.u. losses} \times 135}{50}$$

Again, using these same temperature conditions, the average weight of air per cu. ft. = 0.075 (Table 3) and the specific heat = 0.24, the required volume of air in cubic feet is

$$\frac{\text{Useful heat}}{0.075 \times 0.24 \times 50} \text{ or } \frac{\text{total heat required}}{0.075 \times 0.24 \times 135}$$

16b. Heat Given Up by Indirect Radiators.[1]—The heat transmitted by indirect radiators depends on two things: the transmission factor K, and the mean temperature difference between the fluids. in this case either steam and air or hot water and air. The transmission factor K is the number of B.t.u. per square foot of heating surface per hour per degree of mean temperature difference between the fluids. It varies only with the velocity of the air over the surface.

For cast-iron indirect radiators

$$K = \frac{1}{0.047 + \frac{61}{V}} \quad (1)$$

For pipe coil indirect radiators

$$K = \frac{1}{0.0447 + \frac{50.66}{V}} \quad (2)$$

Diagram 5 gives values of K for various velocities. The writer has assumed that a velocity was known and that the relation would hold true whether the air was circulated by gravity or by fan. The mean temperature difference of fluids transmitting heat through surfaces is, in any case,

$$\theta_s - \theta_m = \frac{\theta_2 - \theta_1}{2.3025 \log \frac{\theta_s - \theta_1}{\theta_s - \theta_2}} \quad (3)$$

where θ_s = temperature of steam or average water temperature.
θ_m = average mean temperature of the air.
θ_1 = temperature of entering air.
θ_2 = final temperature of air.

The Napèrian logarithm = 2.3025 times the common logarithm.

[1] Formulas given were deduced from experiments by F. L. Busey and W. H. Carrier and are considered classic contributions to the science of heating engineering. They are used by all blower and heater manufacturers for their capacity tables.

Diagram 6 gives values of $(\theta_s - \theta_m)$ for various temperature conditions. Let

A = area through heater in square feet.
V = velocity of air in feet per minute, measured at 70 deg. F.
S = total area of heating surface in square feet.
$Q = AV$ = flow in cubic feet per minute measured at 70 deg. F.
C_p = specific heat of air at constant pressure = 0.24.
d = density of air at 70 deg. F. = 0.075 (Table 3).
K = transmission factor.

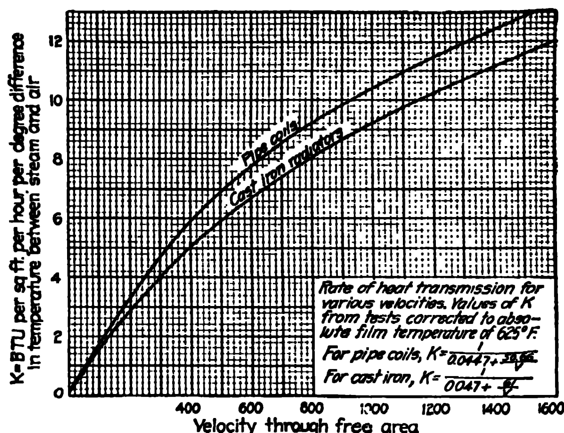


Diagram 5.—Condensation chart to be used in connection with Diagram 6.

The weight of air flowing in pounds per hour = $60\ AVd$.
The total heat radiated in B.t.u. per hour = $KS\ (\theta_s - \theta_m)$.
The heat delivered by the air in B.t.u. per hour = $60\ AVd \times C_p(\theta_2 - \theta_1)$.
The total heat radiated equals the heat delivered by the air:

$$KS(\theta_s - \theta_m) = 60AVdC_p(\theta_2 - \theta_1)$$

from which

$$S = \frac{60AVdC_p(\theta_2 - \theta_1)}{K(\theta_s - \theta_m)}$$

Substituting Eq. (1) for Vento or Eq. (2) for pipe coils and Eq. (3) for $(\theta_s - \theta_m)$, we have the heating surface for cast-iron heaters

$$S = A(0.1175V + 152.5) \log \left(\frac{\theta_s - \theta_1}{\theta_s - \theta_2}\right) \qquad (4)$$

and for pipe coils

$$S = A(0.1118V + 127) \log \left(\frac{\theta_s - \theta_1}{\theta_s - \theta_2}\right) \qquad (5)$$

Substituting $S = fA$ $\left((\text{From } f = \frac{S}{A} = \frac{Ns}{A}\right)$, for cast-iron heaters

$$f = (0.1175V + 152.5) \log \left(\frac{\theta_s - \theta_1}{\theta_s - \theta_2}\right) \qquad (6)$$

and for pipe

$$f = (0.1118V + 127) \log \left(\frac{\theta_s - \theta_1}{\theta_s - \theta_2}\right) \qquad (7)$$

Diagram 6 gives values of f for various temperature conditions.

16c. Illustrative Problem.—Design a heater to furnish heat to room 1, second floor, Fig. 7, p. 1163. From Table 13, total heat loss = 96,430 B.t.u. per hr., cubic contents = 34,272 cu. ft., and air changes due to infiltration = 0.375 per hr.

	Temperature of steam	= 220 deg. F.
Assume	Temperature of atmosphere	= −10 deg. F.
	Temperature of air leaving heater	= 125 deg. F.
	Temperature drop in ducts	= 5 deg. F.
	Temperature of air entering room	= 120 deg. F.
	Temperature of air in room	= 70 deg. F.

$$\text{Total heat required} = \frac{96{,}430(125 - -10)}{120 - 70} = 260{,}360 \text{ B.t.u. per hr.}$$

$$\text{Volume of air necessary} = \frac{260{,}360}{0.075 \times 0.24 \times 135} = 107{,}150 \text{ cu. ft. per hr.}$$

$$\text{Air changes} = \frac{107{,}150}{34{,}272} + 0.375 = 3.12 + 0.375 = 3.5 \text{ per hr.}$$

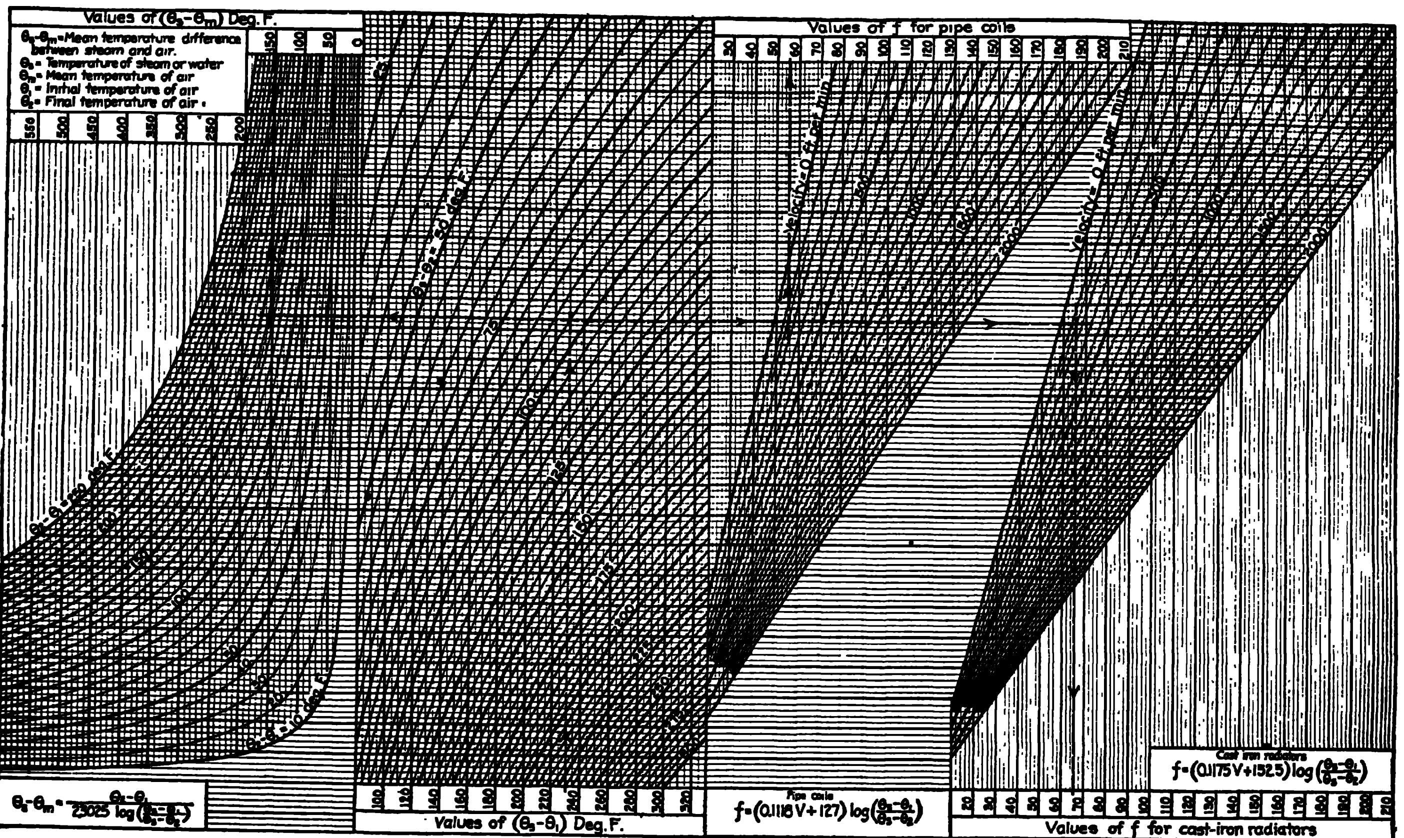


Diagram 6.—Air temperature increments for cast iron and pipe coil indirect radiation under various conditions of steam and water pressures and temperatures.

This is good ventilation, therefore the temperature conditions were well chosen for outside air at −10 deg. F. By inspection, it will be seen that if the temperature of the atmosphere rises, it will reduce the number of air changes, unless tempering dampers and a by-pass for cold air are employed.

The next step in the problem is to decide whether pipe coils or cast-iron heaters will be used. First we will choose to use "Vento" cast-iron heaters. A velocity of 150 ft. per min. from Diagram 5 gives a value of $K = 2.20$; Diagram 6 gives a value of $(\theta_s - \theta_m) = 152.0$; and the free area is $\frac{107,150}{60 \times 150} = 12$ sq ft. If the heating surface is $\frac{280,360 \text{ B. t. u. per hr.}}{2.20 \times 152.0} = 779$ sq. ft., then the ratio $f = \frac{779}{12} = 65$. From Eq. (6), Art. 16*b*,

$$f = (0.1175 \times 150 + 152.5) \log \left(\frac{220 - -10}{220 - 125}\right) = 65.2$$

Values of f may also be read directly from Diagram 6. Start with a value of $\theta_s - \theta_1 = 230$, follow dotted line in direction of arrow up to curve of $\theta_s - \theta_2 = 95$, follow dotted line to the right to the cast-iron radiator diagram to where the velocity = 150 ft. per min., and on the scale directly above, read the value of $f = 65.1$.

These two values of f agree very well, so we can assume $f = 65.2$. Let $f' = \frac{N}{f}$ = sq. ft. of surface per sq. ft. free area per stack. Then, when $N = 1$, $f' = 65.2$; $N = 2$, $f' = 32.6$; $N = 3$, $f' = 21.7$; $N = 4$, $f' = 16.3$; and $N = 5$, $f' = 13.0$. The number of stacks may be varied at will by selecting a radiator of appropriate design from Table 20. Values of f are given for each type of radiator.

In this case, we will assume 4 stacks deep. Then $f' = \frac{65.1}{4} = 16.3$. From Table 20, a regular section "Vento" 9¼ in. wide, 72 in. high, 5 in. c. to c., and with 19 sq. ft. of heating surface per section, has a value of $f' = 17.2$ making $f = 17.2 \times N = 68.8$, or a little above the requirements. The total number of sections in the first stack, or the first row of stacks as the case may be, is

$$\frac{12 \text{ sq. ft. free area}}{1.104 \text{ sq. ft. free area per stack}} = 10.9, \text{ say } 11 \text{ sections.}$$

The total number of sections then is $11 \times 4 = 44$, and the total heating surface is $44 \times 19 = 836$ sq. ft., or some what more than the 780 sq. ft. required.

The width of the air spaces should be a governing factor in selecting a type of section for indirect gravity heating, as the air is liable to pass without being heated if the sections are too far apart. The previous selection of 4 tiers 72-in. Vento would prove bulky and engender difficult construction due to space in many cases. The following tabulation gives four selections with the friction and data comparatively from Table 20, as well as approximate space occupied.

Type of sections	Spacing c. to c. (inches)	Tiers deep	f	Sq. ft. per section	Free area per section	Total no. sections	Total sq. ft.	Friction (lb. per sq. ft.)	Total length × width × depth
72-in. Vento.......	5	4	17.21 × 4	19.0	1.104	44	836.0	0.02904	6′ × 4′ 7″ × 3′ 4″
40-in. Vento.......	4	2	30.71 × 2	10.75	0.35	74	795.5	0.023	3′4″ × 12′ 4″ × 1′ 8″
Perfection........	2⅞	1	66.66	15.0	0.225	54	810.0	0.023	3′ × 13′ × 1′ 3″
Sterling...........	3½	1	66.66	20.0	0.3	40	800.0	0.0203	3′ × 11⅜′ × 1′ 4″

Note that the 40 in. Vento is slightly under requirements. This was adjusted by making the area slightly greater by adding two sections to each tier.

The next requirement is to determine whether with the head available the velocities will be realized. The method of determining the resistance and velocity is as follows: Assume for each flue a horizontal duct 30 ft. long with 3 elbows with a radius of ½ the depth, a flue temperature of 125 deg., two registers with 75% of the flue velocity and an effective height of 20 ft.

The cubic feet of air required per hour is 170,150 or 2820 cu. ft. per minute. The available pressure for 125 deg. and 20 ft. height (Table 26) is 0.287 lb. per sq. ft. Assume 300-ft per min. flue velocity with 3 flues of 3 sq. ft. each, say 12 in. deep. From Table 27, 3 sq. ft. with 0.0045 lb. per sq. ft. drop in 10 ft. will give 942 cu. ft. per min. Assuming a length of 30 ft. in the cold air duct and 3 elbows with a radius of ½ the depth, we will require 30 ft. additional of pipe or 30 + 90 + 20 = 140 ft.

The ratio of the sides being 3 × 1, the actual friction will be for each unit flue

Pipe friction $14 \times 1.18 \times 0.0045$ = 0.0743 lb. per sq. ft. (Tables 27, 30)

Velocity head $0.075 \frac{V_2}{2g} = \frac{25}{64\ 32} \times 0.075$ = 0.0293 lb. per sq. ft.

2 registers—$2 \times 1.25 \times (0.75)^2 \times 0.0293$ = 0.0413 lb. per sq. ft. Eq. 4 Art. 28*c*

Indirect stack sterling =0.0203 lb. per sq. ft. (Table 20)

0.1652 lb. per sq. ft.

This shows there is ample power to overcome resistance at the assumed velocities, also that the Vento stack 4 deep has too great resistance when the outside temperature reaches 50 to 65 deg. for the difference between the flue and outside. The available pressure then is 0.16 lb. per sq. ft. (Table 26)

The steam necessary at 220 deg. F = $\frac{260,360}{965.2}$ = 270 lb. per hr. Where the velocities are high, say around 1200 ft. per min., when fans are used, then proportions of heaters change; the number of stacks is increased and the sections per stack are decreased.

There is very little data on indirect heating with low steam temperatures or with hot water but it is difficult to raise the temperature of the air with only one stack deep. There is no good reason or advantage in using indirect hot water, as, with the circulated air, a constant steam temperature may be used, varying the room temperature with that of the air flow and temperature.

Fan coils are figured in exactly the same manner as for gravity circulation, only with higher velocities. An example is given in Art. 28*d*.

16*d*. Unit Fan Heaters.—Figs. 19 and 20 show a rather recent innovation called unit fan heaters. These are set near the floor with a disc fan and motor to circulate the air in shops and factories. They give a very effective distribution without ducts and the horsepower of the fans is only 1 to 1½ hp. or less, per unit. One unit may handle 50,000 or 60,000 cu. ft. of air per min., and they may be connected with a hot water or steam system of distribution, thus doing away with direct radiation. The type shown is not suitable for hot water, but they may be made up of a fan, casing, and a number of sections of short Vento placed about 6 ft. from the floor level.

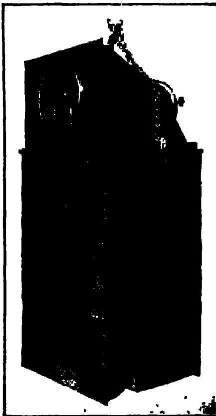


Fig. 19.—Unit fan heater, Sturtevant Co.

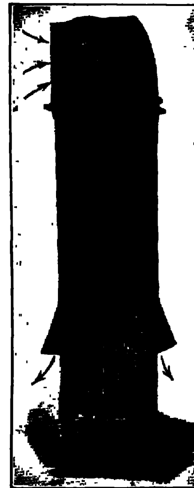


Fig. 20.—Unit fan heater, American Blower Co.

17. Other Systems of Heating.

17*a*. Vacuum Steam Heating.—A vacuum system may be applied to any steam heating plant by placing thermostatic traps on all radiators and drip connections between the supply mains and returns so the piping handling steam will be entirely separated from that taking care of the condensation, except through the thermostatic traps which are all designed to allow air or water to pass but to hold the steam. The system commonly takes the name from the name of the trap; the most common are Dunham (Fig. 20*A*), Warren Webster, McLear, Hoffman, and Marsh.

The returns are all brought to a central point where there is a power vacuum pump operated by steam or electricity to mechanically remove the air and water from the system. The discharge of this pump leads to an air separating tank or receiver from which the water is pumped back to the boiler by the feed pump.

17*b*. Air-line Vacuum Systems.—A modification of the vacuum return system is the vacuum air line system used exclusively in connection with single pipe steam. The vacuum system proper has the *thermostatic* trap at the return of radiator, and air and condensation are removed through the return requiring no air valve on the radiator. Special air valves

on the principle of the *thermostatic* trap are attached to the radiators, which allow air to pass but no water or steam. These are connected together with ½-in. pipe to a ¾ or 1-in. main and led to the basement to a drain or sink. This obviates the nuisance of air valves with their smells and leaks. An ejector or other mechanical apparatus for air removal may be used on the end of the line if desired.

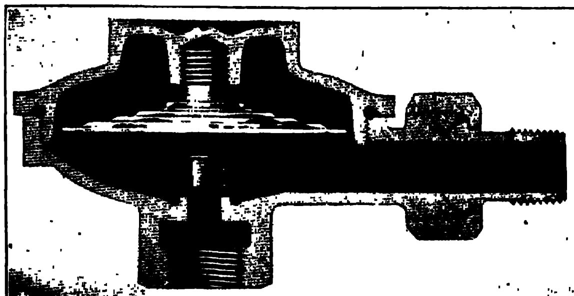


Fig. 20A.—Dunham radiator trap.

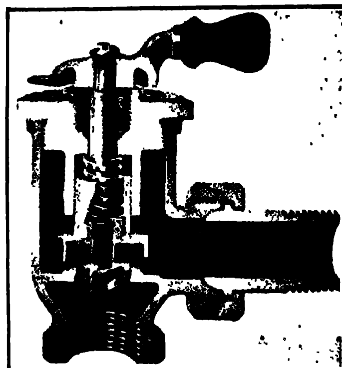


Fig. 20B.—Webster Type N modulation valve, sectional view.

17c. Vapor Systems.—Vapor systems are practically the same as vacuum systems with the mechanical air removal omitted. The same valves and traps are used. The air is exhausted by a large vent on the end of supply and return mains by means of initially raising the pressure on the boiler. After removing the air, the vent on the end of the main automatically seals and if the system can be kept air-tight, the steam will circulate somewhat below atmospheric pressure.

Another method involves an entirely open system with a main vent connected to the boiler flue to obtain a pressure below the surrounding air. Automatic regulators on the boiler controlling the draft prevent any steam pressure above atmosphere. Very slight pressure drops and large pipe sizes for the mains are required to accomplish this. The same principles governing the flow of fluids are involved and special attention must be given to make sure that the pressures throughout the system will equalize quickly. Vapor systems are generally used for house heating and small plants where no exhaust steam is available. Thermostatic control is advisable as there is practically no variation in the temperature of the medium beyond a few degrees. Fractional valves are commonly used on the radiators for both vapor and vacuum systems (Fig. 20B).

17d. Donnelly Positive Differential System.—The positive differential system consists of the following essential parts: (1) a throttling valve for admitting the desired amount of steam to the radiators, (2) an impulse valve on the outlet of each radiator, (3) a positive differential valve located at each return riser for maintaining a standard difference in pressure between the steam supply and return risers.

If the engine were exhausting at ½-lb. back pressure, which would be the pressure in the supply riser and in the radiators when turned on full, the valve on the radiator would be set at ½ lb. to reduce the steam pressure to zero while allowing the discharge of water by gravity through the valve. The differential valves in the branch return are weighed to about 5 lb. per sq. in. (area of the valve seat) which permits a vacuum as high as 10 in. to be carried on the main return.

17e. Vacuum Exhaust Steam Heating.—Where exhaust steam is utilized or where high pressure steam is reduced, a reducing pressure valve is required which opens and closes, governing the supply of steam automatically with the demand. This is composed of a diaphragm and spring which with the valve seat establishes an equilibrium so that a constant pressure is maintained on the low side. Bypass valves are essential so repairs may be made and operation maintained. A back pressure valve is required so if the engine supplies more steam than necessary, the pressure in the heating main will open the valve to the atmosphere

and relieve the system. The back pressure valve also prevents air entering the system. These two pieces of apparatus keep the pressure constant in the mains, an essential point in proper operation and results.

Vacuum systems are used where the exhaust steam is circulated at very low pressures in connection with its utilization from non-condensing steam engines. There is undoubtedly economy in the mechanical removal of air from any steam system. Much is claimed for vacuum systems, but except for removal of air, they are like any other steam systems. The vacuum in the returns cannot reach the steam in the radiators or mains due to the trap. If higher vacuum than corresponds with the return water temperature is carried, cold water must be injected back of the vacuum pump to reduce the temperature, or the condensation, being at a higher temperature than the boiling point at that pressure, vaporizes into steam. From the above it will be seen that a vacuum system can produce no pressure below atmospheric on an engine or turbine at the exhaust outlet. The best results are obtained when about 2 or 3 in. of vacuum are maintained on the return of the radiators or just enough to assure the rapid removal of the air leakage and condensation.

17f. High-pressure Steam.—When high-pressure live steam is used for heating up to 20 lb., the water may be returned to the boiler by a return trap, a tilting tank that alternately connects the tank with the system, filling with water, and then by its added weight due to the condensation, tilting and connecting with the higher pressure steam in the boiler. As the tank is placed above the water line with checks to temporarily shut off the heating system, the water seeks its level in the boiler. When empty, the tank tilts back and an air valve relieves the residual pressure, shutting off the boiler steam. The pressure in the heating system forces in another charge and the operation is repeated.

The same arrangement may be used for kitchen fixtures and high pressure drips on power plants, returning the condensation direct to a high pressure boiler. The circuit being sealed, it is very economical.

17g. Hot Water Heating in Connection with Condensing Reciprocating Engines. It is possible to operate a hot water heating system with partial vacuum on a reciprocating engine but the range in vacuum and steam rate is not very great, due to the necessary changes in compression. The valves have to be set differently for condensing and for non-condensing. There are engines provided with facilities so the valve rods may be changed quickly but there has been serious objection to this practice. The best method is to operate the engine on, say, 10 to 26 in. of vacuum and use additional live steam for the remainder of the heating requirements.

Engines for this purpose should not have too large a ratio of cylinders as they are apt to be unable to carry the load on reduced vacuum; thus economy has to be sacrificed in summer due to engine design in order to utilize exhaust steam in winter.

Many cases have arisen where steam has been tapped from the receiver between the high and low pressure cylinders. This will give good results if the engine is not too heavily loaded but just as soon as the receiver pressure drops, the interference is serious. There have been cases where reducing valve connections have been made to the receiver to help out the heavy intermittent draft for other purposes. It is obvious that this steam should be taken direct rather than by this method; the amount of steam generally that can be bled at this point is about the difference in steam rate between non-condensing and full vacuum, or about 25% of the engine's minimum, full load requirements. The Bleeder turbine exhausting steam from between the stages involves the same principles.

17h. Combined Heating and Power.—It is generally admitted that when current may be purchased at rates below 1.5 cts. per kilowatt-hour, that exhaust steam heating combined with power generation is questionable as a paying investment.

The heating system is a dissipator of heat and no steam engine utilizes more than 15% of the heat of the fuel for actual power, the balance being discharged into a lake or pond in the process of producing a low terminal pressure and high vacuum.

Reciprocating engines for electric power generation due to low speed, space required, and costliness, are being rapidly displaced by the small turbo-generator with high speed and vacuum although this machine is exceedingly uneconomical under non-condensing operation.

Heating is required about 8 months of the year and while exhaust steam heating would prove profitable during that period, additional condensing equipment would be required for summer operation to maintain the economy and prevent the loss in summer of the saving in winter.

The requirements of an economical combined heating and power generating system may be stated as follows:

1. Power cannot be generated under non-condensing conditions in competition with the public service plant with either reciprocating engines or turbines, due to the constant steam power rate.

2. In all cases the engine must of necessity deliver its full rated power load whether there is a heat balance or not.

3. This means an almost constant quantity of exhaust steam due to the fixed terminal pressure at which it must be used on any steam system.

4. The heating and power can only balance at one outside temperature as the heating requirements will vary from 100% in zero weather to less than 50% in moderate weather. Live steam will be required in colder periods and steam will be wasted to the atmosphere during the warmer periods. Therefore a variable steam rate for power is required to balance the heating and maintain the constant power load if the combination is to be a paying investment.

5. The turbo-generator under variable vacuums has a steam rate varying 100% between no vacuum and full vacuum, and hot water forced circulation enables steam temperatures below atmosphere to be used, whereby the variation of the vacuum so produced at the exhaust outlet of the turbo-generator will cause the proper variation in the steam power rate. Therefore, the condensing turbo-generator and forced hot water heating system have all the essential features for an economical combined heating and power system.

The same economical and low cost condensing turbo-generator is employed that is used by the public service companies, with high vacuum at all times summer and winter when heating is not required. When heating is required, the heating system takes its portion of the condensing load, the variable vacuum producing the variable steam power rate, constant power load, and perfect heat balance. Thus a maximum power recovery is obtained from the heating fuel.

17*i*. Evans' "Vacuo" Hot Water Heating System Combined with Power.—The writer has perfected a system of vacuum control on which letters patent are about to be issued, whereby the vacuum on a condensing turbo generator may be varied at will from 3-lb. back pressure to 28 in. of vacuum, independent of the power or heating loads without stopping the machine or opening the relief valve.

The system has been in operation for several years in a large railway terminal in the East and the relations given are from actual test data and are, therefore, reliable.

The saving of 70% in steam as indicated, is not dependent on skill of operation, but is inherent in the physics of the problem. It is one of the easiest means of conserving the fuel of community at a profit by utilizing the heating fuel, steam, and boilers for combined power generation. It is applicable to any heating plant of over 500-hp. capacity in zero weather, such as office buildings, factories, or institutions, as long as there is use for the available electric power during the period the heating system operates.

The arrangement enables the plant to be placed on a proper accounting basis whereby all heat and current can be metered and apportioned according to different departments and operations.

There is a large plant known to the writer wasting about $100 per day in exhaust steam from two non-condensing nozzle turbines used as auxiliaries for a turbo-generator whose entire steam load does not aggregate twice the steam these auxiliaries require. By purchasing 200 hp. in motors, this waste could be eliminated, yet this condition has continued several years.

All fuel and power plant expense is lumped and divided by the number of units per day of the manufactured article. There is a very large machine shop receiving power and heat belonging to a subsidiary company manufacturing presses for outside customers. This expense is all lumped in the articles manufactured by the main plant. They actually do not know what it costs only in a very general way or where the expense should be charged.

Diagram 7 was deduced from an actual problem and reduced to percentages for convenience. If a plant used 100,000 lb. of steam per hr. in zero weather for heating, and a steam rate of 16 lb. per kw-hr. could be obtained with 200-lb. initial pressure and 28 in. of vacuum, the average steam rate, hourly power load, and total recovery would be respectively 16 lb. × 140% = 22.4 lb., $\frac{100,000}{16}$ × 45.3% = 2800 kw. load average, and 2800 × 4900 hr. = 13,720,000 kw.-hr. × 1.2c = $164,640 per heating season of 8 mo. If plant operates 12 hr. instead of 24 hr., the saving would be ½ or $82,320. If the turbine condenser and plant cost $50 per kw. of 6000 kw., the investment would be $300,000, or the debt on the plant would be amortized in less than 2 or 4 yr. This same turbine and condenser is available for power under full vacuum in summer and there would be no idle heating boilers in summer to be covered by interest and depreciation. If boiler operation and fuel is 0.7¢ per kw.-hr. and it costs 1.2¢ per kw.-hr. to purchase current, the summer power load would involve a saving of 0.5c per kw.-hr. in addition.

The 7% area is the actual heat converted into mechanical energy, the 27% area the increase in steam rate due to the reduction in vacuum during colder periods of higher circulating temperatures. The ordinates are the hourly percentages of the 100% of steam required for zero weather heating. The abscissas are relative percentages

of time the diffe nt outdoor temperatures occur from the weather bureau reports. The 73 % area represents the power recovery n pounds of steam at full vacuum or the saving is 73 % of the heating steam.

The lines 26 in., 27 in., and 28 in., are the increases in steam due to apparatus design for the lower vacuums which show the more economical the power machine the less the saving in fuel by utilizing exhaust steam for heating. In this cas e cost of utilizing 75 % of the heating in exhaust steam is 30 % of the power, or ⅓ live steam has to be added t tilize exhaust steam for the heating.

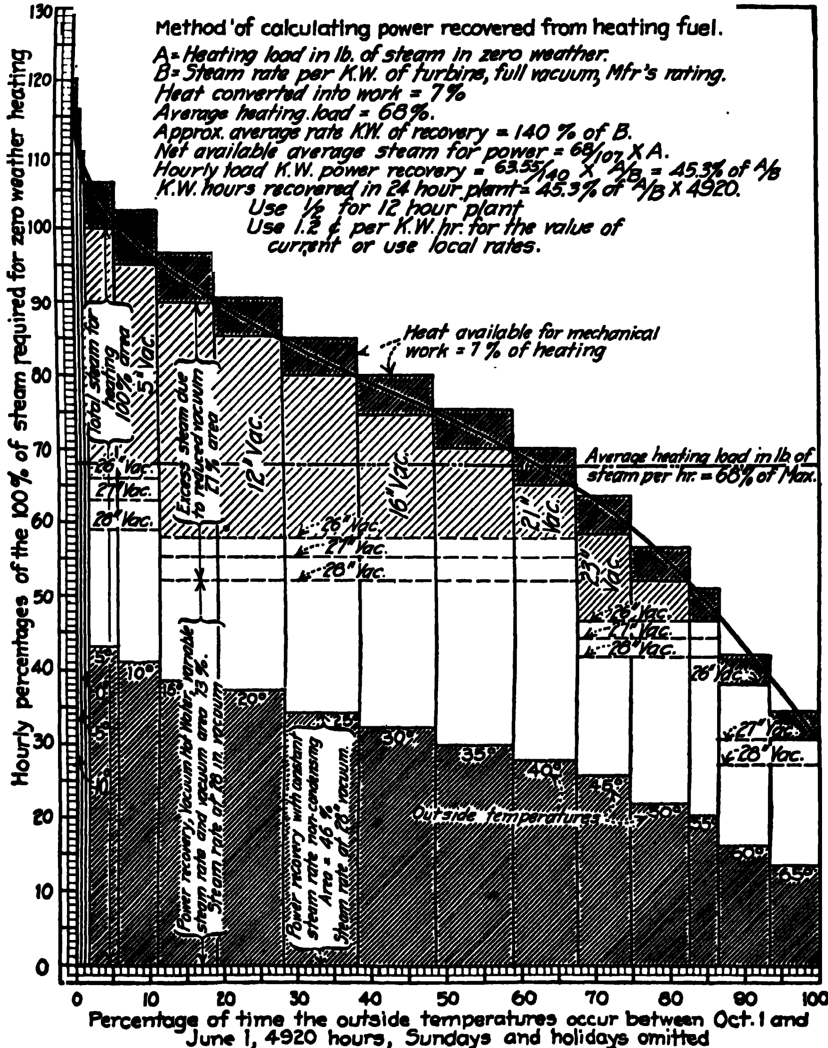


Diagram 7.—Relative fuel saving and mechanical power recovery from the heating plant under condensing and non-condensing operation.

Note the actual variation of the power load is slight. It is constant for 57 % of the time (lines 26 in., 27 in., 28 in. vacuum) and in the warmer periods above 45 deg. the increase in steam rate for proper heating temperature is not over 2 lb. per kw-hr. or less than 10 %, so it is not serious. The degree of regulation obtained on the heating system, as a whole, reduces the total steam over ordinary methods so that in most cases less coal would be burned for heating and power than would be used where the apparatus receives no attention, when outside temperature changes occur. Under ordinary conditions when the temperature drops, it is several hours before the rooms or

apparatus is affected and when the outdoor temperature rises, sometimes a day or two is needed before the system can be adjusted to the changed condition.

Where the heating medium is regulated by the outside temperature at a central point, these weather changes are met long before the buildings and rooms are affected, thus tending to the economical use of heat and greater comfort.

The 46 % area is the recovery of power by use of a bleeder turbine. This machine to operate successfully would have to be at least twice the capacity of the steam bled, this case 8000 to 10,000 kw., and might be larger than the maximum power requirements of the plant. The power recovery would be at the non-condensing steam rate.

If the steam were used on a non-condensing engine or turbine it is readily seen that the wide variation in load due to the constant steam rate would never be met with a single unit. If the average load were balanced, at 30-deg. F. outside, steam would pass to the atmosphere at temperatures above 30 deg. F. and live steam would be necessary at temperatures below 30 deg. F. The actual power recovery would not be more than 25 %.

River or natural cooling water is not obligatory for the success of this system, as cooling towers may be used with equal economy and the savings are more than sufficient to warrant their adoption. They would operate 12 mo. and divide the condensing load with the heating system in winter.

In the middle west the industrial plant situation is in a deplorable condition as far as heating and power are concerned. Although the steam is generated from the fuel generally with good economy, the waste is criminal when applied to power and heating. The policy of the manufacturers is against spending any money for plant improvements that require a term of years to amortize the interest and principal with a saving in operation. The money makes a better showing with the stockholders distributed as dividends.

The fuel in some of these plants amounts to $250,000 per year, but the total expense of power and heating is only 3 or 4 % of the total cost of the manufactured article.

One plant the writer investigated is using 10 lb. of coal in the plant for each kilowatt hour generated at times and the average is 6 or 7 lb. A saving of 25,000 tons per year could be made in this plant on an investment of $500,000. It is in addition, exhausting 12,000 tons per year to the atmosphere from steam hammers, and purchasing $65,000 worth of current for a motor generator 20 ft. from the boilers and out board exhaust head. The 12,000 tons of coal on a low pressure turbine after leaving the hammers would exactly wipe out the $65,000 current expenditure with no fuel to purchase. This saving totals $250,000 a year conservatively calculated and would cut out the operation of 5 boilers or 2000 hp. in a separate plant with all attendant expense. The operation of this plant is notorious among engineers, but it is impossible to persuade the company to take action. Their yearly records showed a continuous increase in the kilowatt rate of about 1 lb. of coal per kw.-hr. per year with an increase in power load. It is with the idea that attention may be brought to manufacturers of the possibilities of remedying these wastes, that this section is given.

18. Comparison of Heating Systems.—The efficiency of any medium of transmission as steam, water, or air depends solely on the physical characteristics of the medium and not on any so-called trade name.

The universal question of "What is the best system?" may be answered by stating that a building can be heated with equal satisfaction by any of the methods, and any system may prove unsatisfactory if it is designed, installed, or operated improperly.

The same building was used as a problem to work out different methods and types of apparatus and these principles apply to all cases regardless of size or type. The same boiler and chimney capacity is required in all the cases and the accompanying table gives the results based on the different assumptions. However, the greater the rapidity of the movement of the fluid through the boiler, the less heating surface required for the same capacity.

The conclusions drawn from the table and problem may be stated as follows:

1. Radiation has nothing to do with the size of the boiler unless accompanied by the temperature of the room and the medium. The heat loss of the building is the actual work to be accomplished.

2. The cost of the plant depends on the amount of radiation which in turn is determined by the average temperature of the steam or water. The lower the working temperature, the more costly the plant.

3. There is practically no difference in the use of steam or water as far as temperatures are concerned and the limits of their application, except that water has a lower and wider temperature range than steam.

4. Raising the pressure on a steam system increases the carrying capacity very rapidly due to the increased density of the steam (from atmospheric pressure to 10 lb., it is increased about 30 %).

5. Size and lack of capacity (in the chimney) are more often the cause of unsatisfactory heating than the type of system (see chimney, boiler, radiation).

6. In all mechanically circulated water systems the rapidity of circulation is independent of the temperatures of the medium. This is not true of gravity circulation, as the height of system and drop in temperature are factors in the determination of the velocity. The average heating temperature is effected as the drop is increased.

7. All mechanically circulated water systems are independent of all grades or distances, as the power is applied externally.

8. The wider the possible range in *average temperature* of the heating medium, the better regulation and possible economy. Moderate temperatures below 210 deg. F. are the most desirable working temperatures for both steam and water.

Schedule	Type and system	Pressure (lbs.)	Average temp. (deg. F.)	Drop in temp. (deg. F.)	Water passed through boiler (cu. ft. per hr.)	Surface (sq. ft.)	Size of main (in.)
"C"	Low pressure steam overhead and from below	5	227	..	25.6	5310	5
"A"	Gravity hot water		210	30	860	5165	6
	Piping from below coils						
"A'"	Forced hot water overhead		210	20	1300	5725	3
"B"	Gravity hot water overhead		170	25	1015	8244	8

9. Air removal is necessary for all steam systems, either through the return with the condensation or through a separate air line. Mechanical methods by pumps are the most satisfactory.

10. The thermostatic traps required on all vacuum systems require cleaning periodically. This is a considerable item in the upkeep of this type of system. Their initial cost should be an item of comparison as they are absent on hot water systems.

11. Due to the constant temperature of the medium on steam systems, risers and mains necessitate the use of covering. This is unnecessary on water systems where the medium for the entire system may be changed in temperature to suit outdoor requirements thereby lowering the required temperature of the circulating medium. Covering is sometimes used to prevent the discoloration of plaster due to dirt collecting along the line of pipe due to convection and movement of air caused by the heated pipe.

19. Selection of a Heating System.—The selection of a system of heating for a building or group resolves itself into two parts:

1. The type of heating surface whether direct, indirect, or a combination of the two.
2. The medium of transmission—water or steam.

(a) Gravity circulation { Hot water / Vapor steam }

(b) Mechanical circulation { Mechanical vacuum system / Forced hot water }

As either medium may be used with any or all types of heating surface, the latter being determined by the utilitarian purpose of the building, or arbitrarily by the desires of the owner, the engineer is mainly concerned with the type of transmission system.

This should be decided entirely on the basis of comparative first cost of installation and operating expense. Where the items are nearly balanced the choice may hinge on other minor disadvantages or advantages of water or steam (liability to damage from bursting or freezing) concerning possible accidental damage which occurs seldom and is generally due to ignorance or careless manipulation.

Consideration of this type of objection should be from the viewpoint of the actuary. The reductions in operating or first cost should be weighed against the probability of the amount of damage occurring over a term of years.

In small plants where the boiler is in direct circuit, either vapor steam or gravity will work out about equally advantageous, until the plant reaches about 3000 sq. ft. capacity. Then forced hot water with a pump and boiler directly in the circuit deserve consideration. The larger the capacity of the plant, the greater the advantage in the first cost of the forced hot water system.

The vacuum valves and their upkeep should be balanced against the pump and cost of current in arriving at a decision.

In all plants of this character where there is only live steam operation and no exhaust, the operating expense will be about the same, the difference being in the lower first cost of the mechanically circulated water arrangement over the vacuum steam arrangement.

When it is desirous to use exhaust steam for heating at atmosphere up to about 300 hp., and there are no long distances, the vacuum steam is available, without change. Steam boilers have to be substituted for water boilers and additional heaters for exhaust steam added to the forced hot water arrangement.

There is no limit to the size of the building or its purpose that will weigh one way or the other in the decision between water or steam, as these matters are covered in the type of heating surface which would be common to either. First cost and operating expense will determine the best selection.

Table 20A.—Approximate Relations of Operating and Installation Costs of Different Methods of Heating Buildings

Type of building	Hot air furnace	Gravity indirect Low pressure steam	Hot blast fan system High pressure steam	Low pressure steam—one pipe air line	Vapor steam—2 pipe with gravity air removal	Vacuum steam—mechanical air removal—2 pipe	High pressure steam—for long distance mains Direct radiation with 10 lb. or vacuum steam	Gravity hot water closed system—210 deg. av. temp.	Gravity hot water open system—170 deg. av. temp.	Forced hot water—boiler in circuit—210 deg. av. temp.	Forced hot water heaters for exhaust blowers—direct radiation or both
	1	2	3	4	5	6	7	8	9	10	11
Residences and small buildings............... 2000 sq. ft. or less of direct heating surface —incidental ventilation	1 A	6 F		2 E	4 D			3 B	5 C		
Garages and car barns...................... Direct heating surface below grade; trenching and excavation for boiler..................			3 C	4 D	5 F	6 E	1 B			2 A	
Stores; lofts; office, commercial, and light manufacturing buildings.................. Live steam, direct heating surface, incidental ventilation..............................			2 C	3 D		5 E	1 B			4 A	
Factory buildings.......................... Exhaust steam under 300 hp. Direct or indirect with fans............................				1 C		3 B					2 A
Factory buildings.......................... Exhaust steam over 500 hp. Direct or indirect with fans.........................				3 C		2 B					1 A
Large public buildings requiring ventilation; schools, courts, jails, etc.....................			2 C	4 *E*		5 D	1 B			3 A	
Office and business buildings, skyscrapers.. .. Exhaust steam over 500 hp.—Direct and incidental ventilation....................				1 C		3 B					2 A
Hospitals and institutions................... Live steam—Direct radiation and incidental fans for ventilation..........................			3 E	4 D		5 C	1 B			2 A	
Hospitals and institutions................... Exhaust steam less than 300 hp. heating surface with ventilation direct...............				2 C		3 B					1 A
Theatres and auditoriums................... Ventilation—paramount.....................			1 A	3 D		4 B				2 C	
Apartments and hotels with isolated plant...... Direct heating surface with ventilation.......				2 C		3 B					1 A
Apartments.............................. No power-plant. Direct heating surface with incidental ventilation.....................				2 C	4 D	3 B				1 A	

* A, B, C, D, order of costs, "A" minimum operation.
1, 2, 3, 4, 5 order of costs, "1" minimum installation.

We come now to groups of buildings heated from a central plant. There are three methods of transmission: (1) High pressure steam with vacuum steam in each building served through a reducing valve, (2) vacuum steam for mains and entire system, and (3) hot water forced circulation.

Institutions where the power load is much less in proportion than the heating requirements, may be handled according to (2) for the nearby buildings utilizing exhaust, and by (1) by those further away.

High pressure steam distribution due to small diameter of main required will prove the most economical method of heat transmission, and by regulating the pressure on a small main and utilizing the drop the steam may be transmitted with a minimum loss of condensed water from the pipe. Exhaust steam, however, cannot be used on a system of this kind.

Low pressure steam, due to the large diameter of pipe necessary and constant operating temperature of the steam, is the most expensive method both for operation and cost of installation. Exhaust steam can only be used at atmospheric pressure or slightly above, and when live steam is necessary at periods of no exhaust, the economy is reduced. Grades have to be carefully observed and traps and drips provided with possibly power pumps to handle the condensation.

Hot water forced circulation enables exhaust steam below atmosphere or live steam to be used with equal facility as no steam is taken outside the power house. The radiation loss from mains is greater than for high pressure steam but not as great as the vacuum steam system. All drips, traps, and vacuum traps are eliminated. Considering turbines may be used and the power recovery from the heating steam for plants over 500 hp. will make this arrangement preferable over any other by a wide margin and the first cost will be no greater than the vacuum steam and possibly less.

The type of radiation effects the cost independent of the system of transmission as follows:

1. Direct radiation generally costs less for operation and installation than indirect.

2. The lower the temperature of the circulating medium, the more surface and greater cost of any type of radiation.

3. Blowers and direct radiation in conjunction cost somewhat more than either alone, but the flexibility is increased and lower temperatures and more satisfactory heating result, with greater economy in the use of heat.

4. The larger the building or plant, the greater the difference in favor of mechanically circulated systems, both from the standpoint of first cost and operating expense. Table 20A is an attempt to classify what is best and the order in which the combinations will work out both from an operating and installation standpoint. This is the writer's judgment from an experience of many years—the 1, 2, 3, etc., and the A, B, C, etc., respectively give the order of the combination as they increase in cost and operation. The experience and ability of the engineer and contractor have considerable to do with the results and in many cases the order will be reversed. The whole is subject to the foregoing discussion.

VENTILATION

20. Quantity of Air Necessary.—Ventilation consists briefly of all the artificial air conditioning necessary to maintain the air inside of a building in a condition desirable for certain purposes, such as for breathing or for making it suitable for given manufacturing processes, and at such standards as may be regarded as desirable.

The most common form of ventilation is that used to furnish an air supply or an air exhaust for the occupants of a building and to keep the interior air from becoming foul—also remove objectionable odors, such as in kitchens, restaurants, and toilet rooms.

In past years the amount of carbonic acid in the air has been used to determine the comparative degree of purity even though it has been understood that carbonic acid itself is not dangerous. This is because pure air seldom contains over 4 parts of carbonic acid in 10,000, while in exhaled air the number of parts rises rapidly and almost proportionately with the other impurities. Therefore, a statement of the amount of carbonic acid present in a given sample of air, a measurement comparatively easy to make, may also be taken as indicative of the amount of other impurities.

Each person gives off about 0.6 cu. ft. of carbonic acid per hour. If the fresh air entering a room has 4 parts of carbonic acid in 10,000, and the limit in the room is desired to be kept below a certain number of parts, the number of cubic feet per minute per occupant must be not less than as follows:

Limit of parts of carbonic acid in 10,000 parts of air	5	6	7	8	9	10	11	12
Cubic feet of fresh air necessary per minute per occupant	133	67	44	33	27	22	19	17

While these are the theoretical amounts of air required, some consideration must be given to the quantity of air contained in the room at the beginning of its occupancy, and also to the length of time the room is occupied. Thus, a church where the services are short and the volume of fresh air is large at the beginning requires less air for ventilation than a moving picture theater running continuously for 10 hr. a day and usually in more or less cramped quarters. The quantity of air necessary for ventilation is measured in cubic feet per minute per occupant or in changes of air per hour. Table 21 shows the cubic feet per minute (C.F.M.) per occupant or the number of changes of air per hour.

TABLE 21[1]

Room	Supply		Exhaust	
	C.F.M. per occupant	Minimum air changes per hour	C.F.M. per occupant	Minimum air changes per hour
Assembly and convention halls	30	8	30	8
Boiler rooms	..	10	..	none
Engine rooms	..	4 to 6	..	8 to 10
Factories	20 to 30	4	20 to 30	4
Foundries	..	4	..	4
Halls and assemblies	30	8	30	8
Mill buildings	20 to 30	4	20 to 30	4
Offices (outside small)	none	..	none	..
Offices (inside small)	..	6	..	6
Offices (large)	20 to 30	..	20 to 30	..
Private office (large)	..	6	..	6
Private office (small)	..	none	..	none
Public offices (large)	..	4 to 8	..	4 to 8
Public offices (inside small)	..	6	..	6
Public offices (outside small)	..	none	..	none
Public toilet rooms	..	none	..	10
Public waiting rooms	..	4 to 6	..	4 to 6
Pump rooms	..	4 to 6	..	8 to 10
Round houses	..	none	..	12
Toilets	..	4 to 6	..	10
Waiting rooms	none	..	..	4 to 6
Hospitals				
Anesthesia	..	8 (with local control)	..	12
Autopsy	..	4	..	8 to 10
Bakery	..	none	..	10
Bath, toilets, etc	..	none	..	12
Boiler (large)	..	10	..	none
Clothes storage	..	none	..	6
Dairy, meats, etc	..	none	..	8
Dark	..	4	..	6
Delivery	60	8	60	8
Dining	20	6	30	8
Doctors wash	..	none	..	8
Dressing	..	none	..	6
Drying closets	..	none	..	20
Electrotherapeutic	..	6	..	8
Engine	..	4 to 6	..	8 to 10
Examination	..	6	..	6
Gymnasium	30	8	30	8
Hydrotherapeutic	..	6	..	8

[1] From Heating and Ventilating Magazine.

TABLE 21 (*Continued*)

Room	Supply		Exhaust	
	C.F.M. per occupant	Minimum air changes per hour	C.F.M. per occupant	Minimum air changes per hour
Hospitals (Continued)				
Ice making	..	none	..	4 to 6
Instrument (Prep.)	..	none	..	6
Isolation	30 to 60	6	30 to 60	6
Kitchens	..	6 to 8	..	15
Laboratories	..	6	..	8 to 10
Laundry (small)	..	none	..	10
Laundry (large)	..	6 to 8	..	12
Lockers	..	none	..	6 to 10
Machinery	..	4 to 6	..	8 to 10
Marking and sewing	..	none	..	6
Meats, dairy, etc	..	none	..	8
Operating	100	10	100	..
Pantries (serving)	...	none	..	12
Plaster	...	4	..	6
Preparation (inst.)	..	none	..	6
Pus dressing	...	5	..	8
Pump and refrigeration	.	4 to 6	..	8 to 10
Recovery	...	8	..	8
Refrigeration and pump	...	4 to 6	..	8 to 10
Serving pantries	..	none	..	12
Sewing and marking		none	..	6
Shops, etc		none	..	6
Solarium	..	4	..	4
Slop sink closets		none	..	12
Sterilizing room		8	..	12
Stores	.	none	..	4
Toilets, baths, etc	.	..	..	12
Utility	..	none	..	12
Waiting	30	6	30	6
Wards (gen'l)	30 to 60	6	30 to 60	6
Wards (contagious)	100	10	100	10
Wash (doctors)	...	none	..	8
Schools				
Auditorium	20 to 30	8	30	8
Board	..	6	..	6
Chemical lab	30	6	30	6
Chemical cabinets	none	none	100 per cabinet	..
Class	30	6	30	6
Coat	none	none	..	8
Commercial	30	6	30	6
Corridors[1]	..	..	..	..
Domestic science	30	6	40	8
Drawing	30	6	30	6
Dress making	30	6	30	6
Forge shop[2]	..	..	..	..
Forges	200 c.f.m.	per forge	400 c.f.m.	per forge
Gymnasium	30	8	30	8
Kitchen for lunch room	..	6 to 8	..	12
Kitchen for cooking class	30	6	50	10
Kitchen (model)	..	6	..	8
Lecture	30	8	30	8
Library	30	7	30	7
Locker	none	none	..	10
Lunch	..	6	..	10
Machine shop	30	6	30	6

TABLE 21. (*Continued.*)

Room	Supply		Exhaust	
	C.F.M. per occupant	Minimum air changes per hour	C.F.M. per occupant	Minimum air changes per hour
(Schools Continued)				
Model apartment	..	4 to 6	..	4 to 6
Office—general	..	6	..	6
Office—private	none	none	none	none
Physical laboratory	30	6	30	6
Recitation	30	6	30	6
Shower baths	none	none	..	10
Swimming pool	..	4	..	10
Toilets	none	none	..	10 to 12
Wardrobes	none	none	..	8
Wood working	30	6	40	8
Hotels				
Ball rooms	30	8	30	8
Banquet hall	30	8	30	8
Bathroom (private)	..	none	..	10
Boiler room (large)	..	10	..	none
Dining	30	8	30	8
Engine (large)	..	4 to 6	..	8 to 10
Kitchen	..	6 to 8	..	15
Laundry	..	6 to 8	..	12
Locker room	..	none	..	10
Pump room (large)	..	4 to 6	..	8 to 10
Toilets (main)	.	none	..	12
Toilets (private)	..	none	..	10
Libraries				
Administration center	..	6	..	6
Book rooms	30	6	30	6
Galleries (public)	..	4	..	4
Galleries (picture)	..	4	..	4
Lecture rooms	30	8	30	8
Locker rooms	..	none	..	10
Lobbies (large buildings)	..	8	..	none
Museums	..	4	..	4
Reading rooms	30	6	30	6
Stack room	..	none	..	4
Toilet rooms	..	none	..	10
Churches				
Auditorium	20	..	20	..
Banquet	30	8	30	8
Coat and locker	none	..	..	..
Sunday School	30	..	30	..
Social rooms	30	8	30	8
Toilets	..	none	none	8 to 10
Theatres				
Auditorium	30	..	30	..
Lobbies	..	10	..	
Retiring rooms	..	4	..	4
Smoking rooms	..	6	..	10 to 12
Toilets	..	none	..	8 to 10

[1] Air supply to corridors should be 4 changes per hour or enough additional to be sufficient to counterbalance the excess of exhaust from all rooms connected to corridors where there is no air supply or where the supply is less than the exhaust.

[2] The air supply to a forge room should be not less than 30 C.F.M. per occupant and should be increased to make up any unbalanced condition occurring when the forges are all running, each being supplied with 200 C.F.M. air blast and 400 C.F.M. forge exhaust.

21. Methods of Ventilation.—There are three general methods of accomplishing ventilation: (1) The supply of fresh air at 70 deg. F. with slight increase in temperature furnishing the necessary heating increment and the exhaustion of an equal amount by means of fans; (2) exhaust ventilation only, depending on chance inlets for a replacement; and (3) the supply of fresh air with either gravity vent flues or none at all. Obviously the first is preferable from a standpoint of efficiency and results.

22. Position of Inlets and Outlets.—It has been found that the most suitable position for the air inlets and outlets in class rooms of schools is in a cross wall at right angles to the outside wall of buildings. The inlet should be as near the inside wall as practicable, about 10 ft. from the floor, and the outlet near the outside wall at the floor level. The air will then pass along the inner wall, returning along the outside wall to the vent flue.

There has been considerable controversy in the past as to the best position of inlets and outlets for ventilating systems. The question is purely one of temperature, the colder air (whether foul or fresh) seeking the lower level, always in proportion to its relative temperature and weight. This temperature will be governed somewhat by the volume of entering air, in proportion to the cubic contents of the room and the temperature of the air in the room. If the change of air in the room is sufficiently often to prevent a rise in temperature inside the

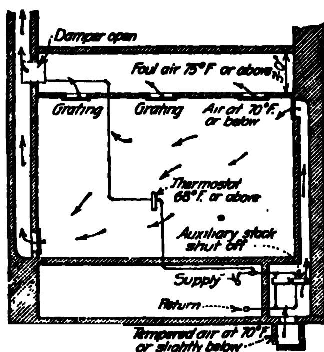


Fig. 21.—Auditorium occupied, auxiliary stack inoperative, damper open, top ventilation neccessary.

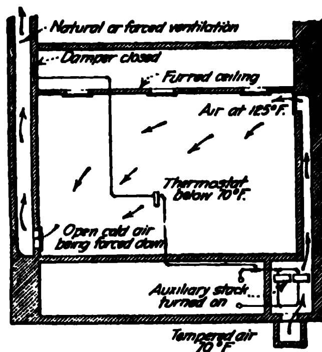


Fig. 22.—Bottom ventilation only required when heating unoccupied auditorium, top damper closed, auxiliary stack operating.

room, there will be but small difference in the weight and temperature of the contained air and the incoming air. If the air change is such that there is a considerable difference in temperature of the entering air and the air contained in the room, the entering air will fall to the floor, due to its greater density if at a lower temperature. Cold air and hot air will not mix until diffusion with interchange of heat has had time to take place.

If these facts are carefully considered, the proper position of outlets can be predetermined. In all problems involving large assemblages of people, the object is to cool the room rather than to heat the space, due to the amount of heat supplied by the audience.

In the ventilation of auditoriums, whether fan or gravity is used, the foul air must be removed at the top due to its extreme temperature after a period of operation, as the temperature may be as high as 100 or 120 deg. F.

Figures 21 and 22 show the arrangement used for ventilating and heating several large court rooms in an eastern city, and show why top ventilation is needed when the auditorium is occupied, and why the top outlet should be closed when the room is being heated. This is true of all auditoriums, as when heating alone is desired, the entering air must be warmer and ligher than the air in the room and the outlets should be at the bottom. When the occupants exhale air and bodily heat is radiated, the foul air of any room containing a large number of people in proportion to the cubic contents is lighter than the incoming air, and the outlets should be at the ceiling. For a perfect system, both top and bottom ventilation should be provided.

A register at the top of the room should automatically close when the room is below the temperature of the incoming air, and open when conditions are reversed. The register may be operated in conjunction with automatic heat control on direct radiation in the room, or on the auxiliary stack in the fresh air supply.

In schools the size of the ordinary class room, the frequent air change required prevents any wide difference in temperature in the room, and the top register is generally dispensed with. The best practice is to heat the room by direct radiation, independent of the air supply, especially during sessions.

23. Preheating Air for Ventilation.

23a. Double-duct System.—This method of heating and ventilation involves a double-duct system, one for tempered air and one for hot air, the two being mixed at the base of the supply flue by means of a mixing damper controlled by a thermostat in the room. There is also heat control at the fan for both tempered and hot air. The method is complicated and should be avoided. The reasons for this are as follows: The rooms are located different distances from the fan, with different conditions existing in the room, the thermostat in the room is expected to set the mixing damper so as to proportion a mixture of tempered and hot air with varying temperature differences. With the losses in ducts, different requirements in the rooms not accounting the fact that the conditions in any case may be reversed, it would be impossible to obtain any accurate adjustment of the system.

This system has been tried again and again without success in the last 40 yr. regardless of many claims to the contrary. There are simpler methods wherein the variables are under control to a greater extent.

23b. Combination Direct and Indirect System.—The heating may be accomplished by a separate direct heating system with sufficient radiation to counterbalance the wall and glass losses. The temperature may be maintained about 10 to 15 deg. below 70 deg. F. when the room is unoccupied. This is more economical than using the fan system during periods when the rooms were unoccupied, as in schools. All fan systems require excessive boiler power in zero weather although the requirements are somewhat below that of direct radiation in moderate weather. Automatic heat control should be provided in connection with properly designed and operated ventilation system.

23c. Individual or Centralized Auxiliary Stacks.—For buildings where direct radiation is undesirable, a very positive and efficient method is to provide a central heating chamber and fan to heat the air to 70 deg. F. or slightly below that temperature. Auxiliary stacks are placed at the base of each flue and controlled by the room thermostat to provide additional heat for strictly heating purposes. By-pass dampers, arranged to pass the air at 70 deg. F. around the auxiliary stack or to pass it through the surface reheating it to above 70 deg. F. may be used. This type of damper does not need to be graduated in its action as it may be wide open or closed.

A modification of the individual stacks is to group several flues with one large auxiliary stack, having the wall chase extend below the stack level, with a damper arranged to be operated by a thermostat in each room so as to take air above 70 deg. F. from above the stack or at 70 deg. F. from below the stack as the case may require. The last room to be brought up to temperature will have the power of the entire stack. The thermostats controlling the dampers are arranged in series so the steam is shut off from the entire stack when the rooms are all taking air at 70 deg. F. This would apply to buildings more or less continuously occupied. Exposed or concealed direct type of radiators may be used installed in the rooms with the air supply blown through them.

24. Theaters and Auditoriums.—A very cheap and successful method of ventilating theaters and churches with high ceilings and places where large numbers of people congregate intermittently, is as follows: Place a large ventilator, with as little resistance as possible, on the roof and provide it with a damper thermostatically controlled to shut off when heating is required and the place is unoccupied. Provide the fan and heater with a series of outlets at a fairly high level where convenient space may be had with automatic heat control on the heating stacks. The thermostats should be operated by the incoming air which should be about 65 deg. F. if the inlets are high enough.

The roof ventilator damper may be controlled by the room temperature, the higher the position of the thermostat, the higher the temperature at which it should be set. When the audience has assembled, more than sufficient heat will be supplied to operate the thermostat, and the vitiated air will pass out of the roof ventilator. The fresh air will fall gradually, due to its weight, and diffuse without perceptible draft. Some experiment and observation is necessary in each individual case to properly set the thermostat. If properly proportioned and adjusted, this system will give excellent satisfaction.

Fig. 23 shows an economical and efficient method of ventilating a moving picture theater. Many of these have an exhaust fan at the rear, but little or no provision for fresh air supply. A supply of fresh air is more important than is the removal of foul air. With only the exhaust system there can be no real certainty from where the air is coming. If fresh air is forced into a building with power, there is greater certainty that it will reach the points intended. In all of this class of work both air supply and air exhaust should be provided, so there will be

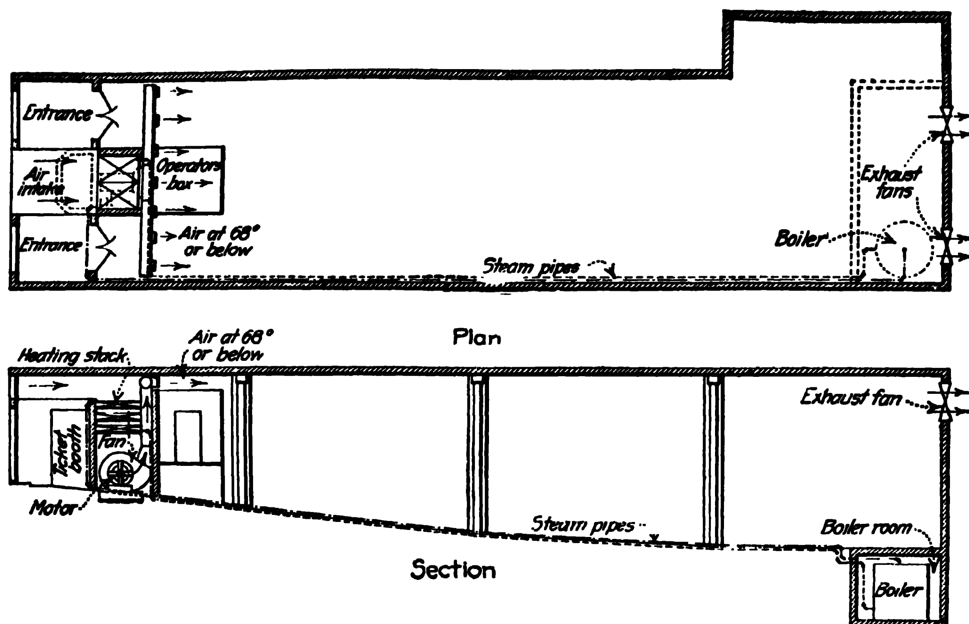


FIG. 23. Arrangement for heating and ventilation of moving picture auditorium.

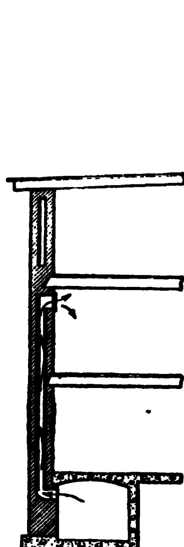


FIG. 24.—Hot air heating flues within building walls.

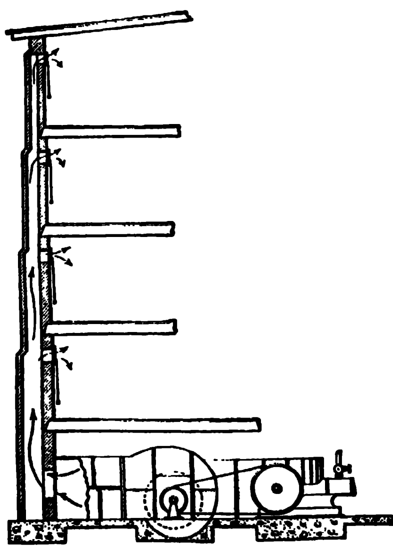


FIG. 25.—Hot air heating flues outside building walls.

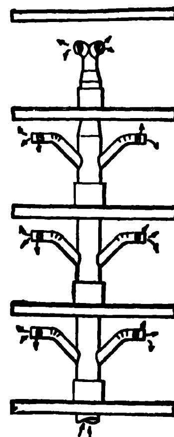


FIG. 26.—Hot air heating, standpipe method.

no question of obtaining fresh air nor any doubt as from where it is coming. Both supply and exhaust should be mechanically operated by fans, with sufficient heat to provide proper temperature and obviate drafts.

25. Methods of Air Distribution.—Figs. 24 and 25 show methods of air distribution for hot blast systems for factories, one with the flues within the wall, and the other with them on the outside, both supplied by an underground duct system.

These systems are very expensive to operate due to the high initial temperature necessary to overcome the loss of temperature in the underground duct. In some cases there will be as high as 60 deg. difference between the temperature of the air leaving the apparatus and that entering the room. This may be made up by increasing the volume of air but it does not reduce the expense, especially with air leaving the heater at 120 to 150 deg. F. Insulation of the ducts will prevent some of the loss but at no inconsiderable expenditure.

Both of the above methods place the larger portion of the cost of the heating system in the building construction contract. If for any reason an allowance for ducts and flues is required afterward, it is not likely to be the actual expense. Separate prices should be taken from the building contractor and all duct and flue work charged to the heating system in order to determine the true cost of such a method of heating.

Fig. 26 shows what is known as the stand pipe method of distribution. This takes considerable floor space but reduces the radiation loss from ducts. The use of the hollow concrete building columns making the annular space into air distributing ducts with the air supply from above and the fans on the roof, makes a very desirable and economical arrangement.

Where only fan heating or indirect radiation is used, a large part of the air supply temperature is absorbed by the masonry, overheating the upper floors while the first two floors are cold. A combination of direct radiation, as hereinafter described, will obviate this difficulty by reducing the air temperature as well as the required volumes.

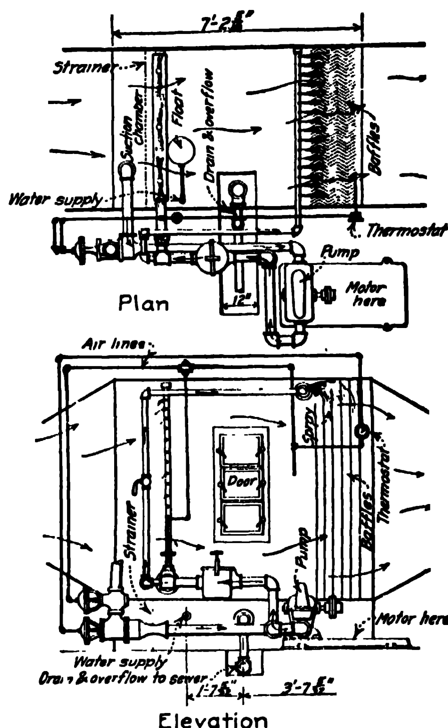


FIG. 27.—Carrier air washer.

26. Air Washers.—Air washers (Fig. 27) are installed for one or all of three purposes: (1) for cleansing and washing air for ventilation, (2) for the humidification or adding the moisture required to condition the air in the rooms to produce comfort, and (3) for cooling and dehumidifying the air for ventilation in summer.

They are placed between the air inlet and the fan. Two sets of coils are used in connection with the air washer, one, known as the tempering coil, to raise the air to near the dew point or 40 deg. F. when the outdoor air is below this temperature; the other, known as the heating coil, to give the saturated air the final increment of temperature after passing the washer, which determines its final temperature and percentage of humidity.

27. Automatic Temperature Control.—Automatic temperature control systems consist of (1) a thermostat placed at the point in the room or place where the temperature is to be regulated, (2) an hydraulic or electric motor driven air pump to furnish air pressure to actuate diaphragm valves or dampers, and (3) the air piping system interconnecting the diaphragms.

Furnace draft regulators consist of (1) the thermostat and (2) the small dry cell motor which regulates the furnace drafts.

The use of thermostatic regulation will prove economical as it will save 25 to 30 % of the heat used in individual rooms. This saving is the same for all systems whether water or steam, *where a constant temperature of the medium is maintained.* Where the temperature of the medium may be varied with the outside weather, individual room regulation may be dispensed with. On indirect systems in connection with heating air, it is indispensable for controlling the temperatures if economical and satisfactory results are to be obtained.

28. Duct and Fan Design.—Ducts and flues for heating and ventilating are usually constructed of galvanized iron or masonry. When galvanized iron is used, they may be round or oblong in shape and are often built of No. 24 U. S. gage up to 350 sq. in. of area, No. 22 U. S. gage from 351 to 1200 sq. in. of area, and No. 20 U. S. gage above this, with suitable stiffeners. Casing for heaters, fan connections, fresh air intakes, and other large compartments are usually built of No. 18 U. S. gage.

Ducts and flues are generally made in the shape of sections and joined up on the job, special connections being installed after the main lines are in place. There are various methods employed by different contractors for joining the various sections, some of the more common

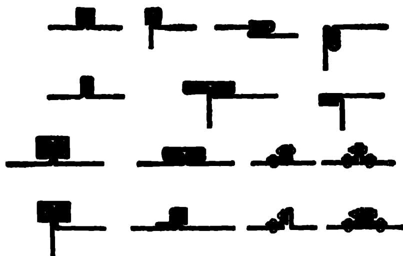


Fig. 28.—Methods of stiffening and locking seams for air ducts.

types being here illustrated (see Fig. 28). For smaller work the use of an angle iron is unnecessary, the standing seam giving all the stiffness required for short spans, but for spans over 4 ft.—and certainly for spans over 6 ft.—angle irons are desirable. Some engineers specify that ducts shall be stiffened "so as to bear the weight of a man on a plank laid along the top at any location selected." Flat seams are little used in good work unless the size of the pipe is 12 in. or less.

Round pipes from a purely efficiency standpoint, are always the best, the amount of metal required to furnish a given amount of air at a given velocity being less and the friction or resistance to the passage of the air also being reduced. In factories, shops, and other industrial buildings, round ducts and flues are the rule; in better classes of buildings, where space is at a premium, square or rectangular flues are used most exclusively. The length of the long side of a rectangular flue should never be more than three times the length of the short side unless absolutely unavoidable.

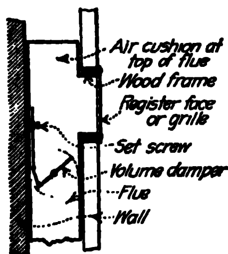


Fig. 29.—Arrangement of volume damper in flue inlet.

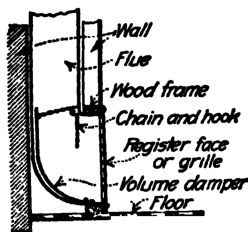


Fig. 30.—Arrangement of volume damper for vent flue.

Volume dampers should be placed so as to control with absolute certainty the quantity of air delivered to each outlet or inlet and it is impractical to try to design a system where such dampers are not needed.

In Fig. 29 is illustrated an up-feed supply system outlet in which the vertical flue is carried a slight distance above the top of the outlet in order to form an air cushion and to help equalize the air flow across the register face. This distance, which is usually made 8 to 12 in., does not absolutely equalize the air flow but tends to prevent such a large quantity of air shooting out through the top third of the register as would be the case if a plain elbow were used.

Fig. 30 illustrates a similar outlet for an up-feed exhaust system with a volume damper consisting of a piece of curved sheet metal riveted to the flue at the bottom and hooked to the proper position at the top by means of the chain and hook shown. The spring of the metal will hold this damper tightly in its proper place after being adjusted. To operate this damper, a hinged or removable register must be used and, for this reason, some engineers prefer controlling air in the flue from a damper located in the horizontal duct connecting to the top of the flue.

Table 22 gives gages and proper weight for galvanized-iron duct systems.

TABLE 22.—PROPER GAGES AND WEIGHTS OF ROUND G. I. PIPE AND ELBOWS FOR DUCT SYSTEMS

Compiled by Heating and Ventilating Magazine

Gage and weight per square foot	Diam. of pipe (in.)	Weight per lineal foot (lb.)	Weight of full ell (lb.)	Gage and weight per square foot	Diam. of pipe (in.)	Weight per lineal foot (lb.)	Weight of full ell (lb.)
28 g. 0.78 lb.	3	0.7	0.4	20 g. 1.66 lb.	38	18.2	139.4
	4	1.1	0.9		39	18.7	146.0
	5	1.2	1.2		40	19.1	152.9
	6	1.4	1.7		41	19.6	160.7
	7	1.7	2.3		42	20.1	168.6
	8	1.9	2.9		43	20.6	176.7
26 g. 0.91 lb.	9	2.4	4.3		44	21.0	185.0
	10	2.7	5.3		45	21.5	193.4
	11	2.9	6.4		46	22.0	202.2
	12	3.2	7.6	18 g. 2.16 lb.	47	29.2	274.3
	13	3.4	8.9		48	29.8	286.6
	14	3.7	10.4		49	30.4	298.8
25 g. 1.03 lb.	15	4.5	13.5		50	31.0	309.9
	16	4.7	15.1		51	31.6	322.5
	17	5.0	17.0		52	32.2	335.1
	18	5.3	19.1		53	33.0	349.7
	19	5.6	21.4		54	33.6	363.4
	20	6.0	23.9		55	34.4	377.2
24 g. 1.16 lb.	21	7.0	29.6		56	34.9	390.7
	22	7.3	32.3		57	35.6	405.1
	23	7.7	35.6		58	36.1	418.8
	24	8.0	38.6		59	36.7	433.1
	25	8.3	41.7		60	37.4	448.6
	26	8.7	45.1	16 g. 266 lb.	61	46.7	569.7
22 g. 1.41 lb.	27	10.9	59.1		62	47.5	589.0
	28	11.4	64.2		63	48.3	608.6
	29	11.8	68.6		64	49.1	628.5
	30	12.2	73.4		65	49.8	647.4
	31	12.6	78.3		66	50.5	666.6
	32	13.0	83.4		67	51.3	687.4
	33	13.5	88.9		68	52.1	708.6
	34	13.9	94.3		69	52.8	728.6
	35	14.3	99.9		70	53.6	750.4
20 g. 1.66 lb.	36	17.2	124.4		71	54.3	771.0
	37	17.8	131.4		72	55.1	793.4

In this table the weights include rivets, solder, and due allowance for trimming and laps; the elbows have an integral radius equal to the diameter of the pipe. Rectangular pipes are usually made of same gage as round pipes of equal area.

28a. Mechanical Circulation of Air in Ducts.—Diagram 8 shows the friction loss in ducts for hot blast apparatus as recommended by the American Blower Company. Diagram 9 is a generally accepted formula and curves of friction factors for sheet iron ducts. The formula is in feet head of air and can be converted into inches of water by multiplying the result by $\frac{12}{62.4}$ when the result is obtained in feet head of air. Pounds per square foot is the weight per cubic foot of the air at the temperature in question.

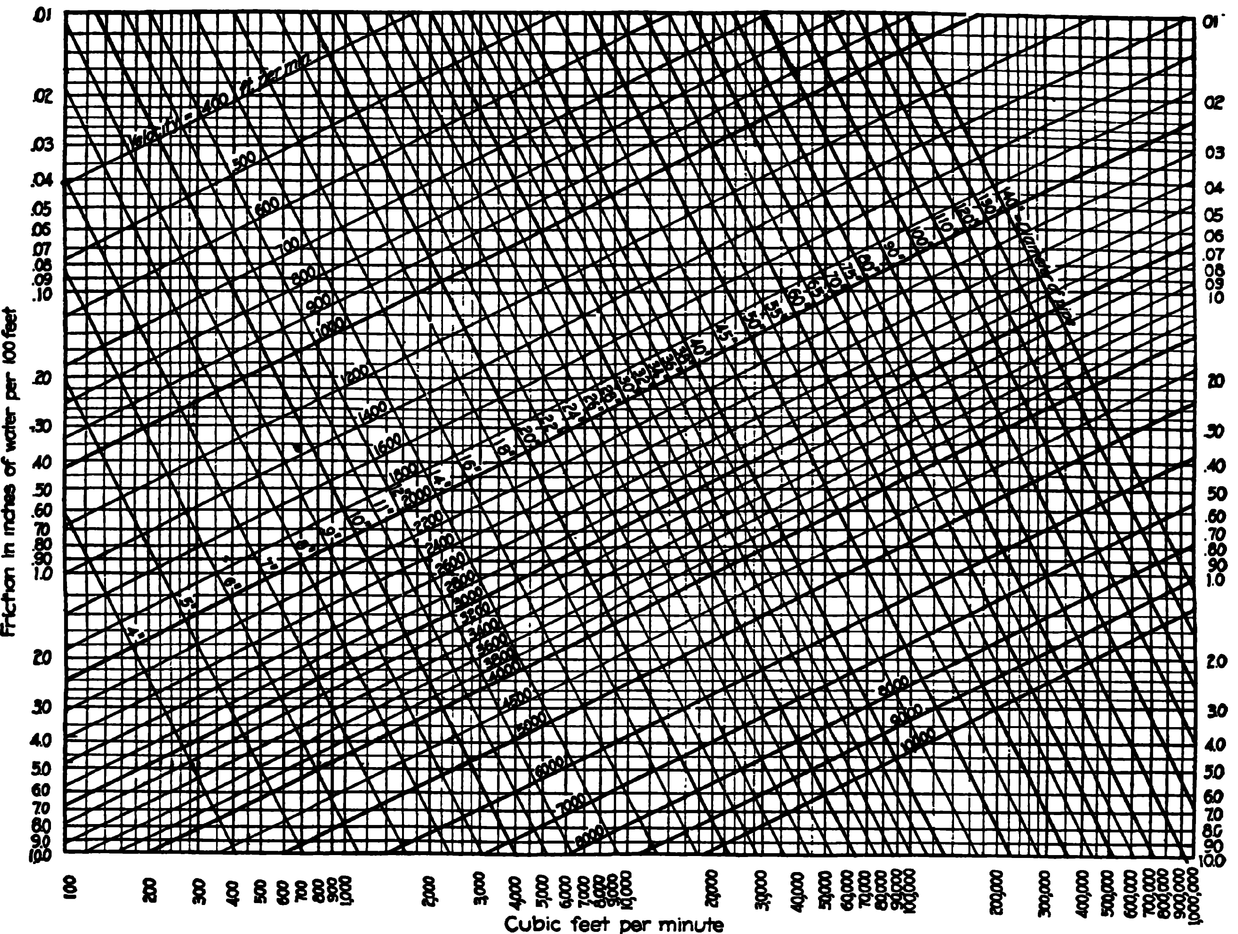


DIAGRAM 8.—Frictional resistance to flow and capacities of air discharge of round sheet iron ducts.

The friction chart gives the results for round pipe velocities and discharge, and friction in inches of water. In figuring a duct system, the velocity head and friction of heaters and air washers has to be taken into account and the whole must be less than the static pressure produced by the fan. The velocity head in inches of water $= h_v = \left(\frac{V^2}{4155.6}\right)$ where V is the velocity in feet per minute. To change the circular ducts to square or rectangular ducts for the same service, use the formula $D = \frac{4 \times A \times B}{2(A + B)}$, in which A and B are the sides of the rectangular duct.

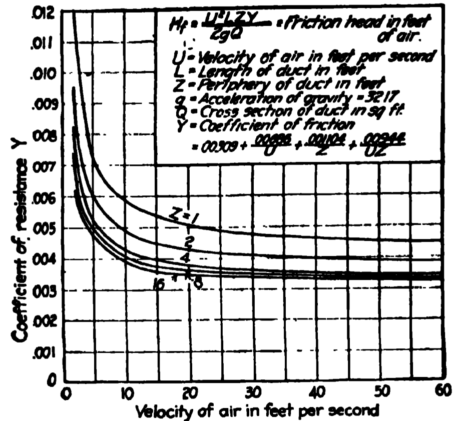


DIAGRAM 9.—Curves of coefficients for friction formula. Flow of air in air ducts.

28b. Air Friction Through Coils, Radiators, Air Washers, Etc.—Table 23 gives a condensed tabulation of the resistance of various standard pipe coils and Vento radiators as used in connection with fans. The resistance varies directly as the number of sections deep,—*i.e.*, 4 sections have twice the resistance as 2 sections for the same velocity. The friction varies as the square of the velocity. If the friction for 2000-ft. velocity is desired, it will be 4 times the friction at 1000-ft. velocity, or if that for 300-ft. velocity per minute is desired, it will be 0.25 of the friction for 600 ft. per min. The velocity through air washers should never be over 700 ft. per min.

TABLE 23.—FRICTION THROUGH HEATER COILS, RADIATORS, AND AIR WASHERS

(in. of water). Nominal 1-in. pipe = 1.28 in. outside diameter—1¼-in. pipe = 1.66 in. 4 rows to section

Velocity through free area (ft. per min.)	Number sections deep	Mitre type, 2⅝ in. c. to c., 1-in. pipe.	2⅝ in. c. to c., 1¼-in. pipe.	Return bend heater, 2⅝ in. c. to c., 1-in. pipe.	2¾ in. c. to c., 1-in. pipe.	A. B. C. heater, return bend type, 1-in. pipe.	Vento regular section 4⅝ in. c. to c.	Vento regular section 5 in. c. to c.	Vento regular section 5⅜ in. c. to c.	Vento narrow section 4⅝ in. c. to c.	Vento narrow section 5 in. c. to c.	Vento narrow section 5⅜ in. c. to c.	Webster air washer.	Carrier air washer.
f′ per sec.	4P = 1 sec.	19.6	21.6	12.33	11.26	18.1	20.5	17.34	14.6	14.3	12.2	10.3		
600	2	0.06	0.06	0.04	0.04	0.022	0.043	0.040	0.034	0.032	0.03	0.026		
	4	0.09	0.09	0.06	0.06	0.044	0.084	0.076	0.064	0.061	0.055	0.047		
	6	0.12	0.13	0.08	0.08	0.066	0.126	0.112	0.094	0.09	0.08	0.069	0.36	0.33
	8	0.15	0.17	0.11	0.11	0.088	0.168	0.149	0.124	0.119	0.105	0.090		
800	2	0.10	0.10	0.07	0.07	0.04	0.077	0.070	0.060	0.058	0.052	0.046		
	4	0.16	0.16	0.10	0.10	0.08	0.150	0.135	0.114	0.109	0.097	0.084		
	6	0.22	0.23	0.14	0.14	0.120	0.224	0.200	0.167	0.160	0.142	0.123	0.64	0.588
	8	0.27	0.30	0.19	0.19	0.160	0.300	0.265	0.221	0.212	0.187	0.161		
1000	2	0.16	0.16	0.11	0.11	0.062	0.120	0.109	0.094	0.090	0.082	0.072		
	4	0.25	0.25	0.16	0.16	0.124	0.235	0.211	0.178	0.171	0.152	0.132		
	6	0.34	0.36	0.23	0.23	0.186	0.350	0.313	0.262	0.251	0.223	0.192		
	8	0.43	0.47	0.29	0.29	0.248	0.47	0.415	0.346	0.332	0.293	0.251		

Friction varies as the square of the velocity.
Friction varies directly as the number of stacks deep.
Multiply by 5.19 to change to pounds per square foot.

Table 24 shows the general practice as to the assumed velocities of air through ducts for different classes of work.

Table 25 is an equalization table for pipe sizes for duct work and is used in the same manner as the one previously given for iron pipes.

TABLE 24.—AIR VELOCITIES THROUGH DUCTS

Velocities in feet per minute	Maximum velocities		Recommended velocities	
	Schools, theaters, churches, and public buildings	Machine shops, foundries and factory buildings	Schools, theaters, churches and public buildings	Machine shops, foundries, and factory buildings
Through fan outlet	2000	2500	1600	2000
Through heater	1400	1800	1000 to 1100	1200 to 1300
Through horizontal ducts	1200	2500	900 to 1000	1200 to 2000
Through vertical risers	750	2000	600	1000 to 1600
Through register or outlets	450	1600	353	600 to 1200
Through intake ducts	1400	1700	1000	1200
Peripheral speed fan wheel	3500	....	2700 to 3000	3000 to 4000

28c. Gravity Circulation.—In figuring ducts for gravity ventilation, the method described in Conrad Meier's "Mechanics of Heating and Ventilation" is used. The formulas are as follows:

Let h = height of flue in feet.
T_f = absolute temperature of flue.
T_o = absolute temperature outside.
P_r = pressure to overcome resistance of construction, in pounds per square foot.
P_f = pressure in pounds per square foot due to friction.
P_v = pressure in pounds per square foot to create velocity.
d = diameter in feet.
c = perimeter in feet.
a = area in square feet.
Q = cubic feet second at 70 deg. F.
v = velocity in feet per second.

Total pressure created in pounds per square foot:

$$P = 0.075\left(1 - \frac{530}{T_f}\right) h \text{ for heat flue above 70 deg. F.} \quad (1)$$

Total pressure created in pounds per square foot:

$$P = 0.075\left(\frac{530}{T_o} - 1\right) h \text{ for vent flues at 70 deg. F.} \quad (2)$$

Pressure in pounds per square foot to overcome friction:

$$P_f = 0.075 \times 0.00624\frac{(V)^{1.9}}{2g} l \left(\frac{c}{a}\right)^{1.18} \quad (3)$$

Pressure to overcome various resistances:

$$P_r = 0.075 \times 1.25r\frac{(V)^{1.9}}{2g} \quad \text{(lb. per sq. ft.)} \quad (4)$$

Pressure to created velocity:

$$P_v = P - (P_f + P_r) \quad (5)$$

Actual velocity obtainable:

$$v = \sqrt{2g\frac{P_v}{0.075}} = \frac{Q}{a} \quad (Q = \text{cu. ft. per sec. at 70°F}) \quad (6)$$

$$\text{Theoretical velocity} = V = \sqrt{2g\frac{P}{0.075}} \quad (7)$$

In Table 26, the available power for gravity flue is given, taken from Meier's charts, and in Table 27 the friction for lengths and discharge of square ducts of various areas are given. In Table 20 on indirect radiation previously given, the resistance in pounds per square foot is tabulated for the various types and sizes one section deep for 150-ft. velocity per minute. For any other velocity, square the proportional difference, *i.e.*, twice the velocity

TABLE 25.—EQUALIZATION TABLE

This table is based upon the laws of friction of gases in pipes, and is designed to equalize the combined capacities of a number of small pipes to that of the main conduit.

Illustrative Problem.—It is desired to connect thirty 8-in. pipes to one main, the problem being to determine the diameter of the main. The usual rule would be to multiply the area of an 8-in. pipe by 30, resulting in a 44-in. main. By the table it will be seen that thirty 8-in. pipes require a main of only 31 in. in diameter to carry the same volume of air. The figures at the top of the column are the diameters of the branches, those at the left-hand side the diameter of the mains. Bold faced numerals indicate diameters of pipes; light faced numerals indicate equivalent number of pipes.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
1																														
2	5.7																													
3	16	2.7																												
4	32	5.7	2.3																											
5	56	9.7	3.6	1.8																										
6	88	16	5.7	2.8	1.6																									
7	129	23	8.3	4.1	2.3	1.5																								
8	180	32	12	5.7	3.2	2.1	1.4																							
9	244	42	16	7.6	4.3	2.8	1.9	1.3																						
10	317	56	20	9.9	5.7	3.6	2.4	1.7	1.3																					
11	402	71	26	12	7.0	4.5	3.1	2.2	1.7	1.3																				
12	501	88	32	16	9.0	5.7	3.8	2.8	2.0	1.6	1.2																			
13	613	107	39	19	11	6.9	4.7	3.4	2.5	1.9	1.5	1.2																		
14	737	129	47	23	13	8.3	5.7	4.1	3.0	2.3	1.8	1.5	1.2																	
15	876	152	56	27	16	9.9	6.7	4.8	3.6	2.8	2.2	1.8	1.4	1.2																
16	1026	180	65	32	18	11	7.9	5.7	4.2	3.2	2.6	2.1	1.7	1.4	1.2															
17	1197	208	76	37	21	13	9.2	6.6	4.9	3.8	2.9	2.4	2.0	1.6	1.4	1.2														
18	1375	239	88	43	24	16	10	7.7	5.7	4.3	3.4	2.8	2.3	1.9	1.6	1.3	1.2													
19	1580	275	100	49	28	18	12	8.8	6.5	5.0	3.9	3.2	2.6	2.2	1.8	1.5	1.3	1.2												
20	1775	312	114	56	32	20	14	9.9	7.4	5.7	4.5	3.6	2.9	2.5	2.1	1.7	1.5	1.3	1.1											
21	1985	345	130	61	35	22	15	10	8.4	6.3	5.2	4.1	3.2	2.6	2.3	2.0	1.6	1.4	1.2	1.1										
22	2250	398	145	71	41	26	18	13	9.3	7.2	5.7	4.5	3.7	3.1	2.6	2.2	1.9	1.7	1.4	1.3	1.1									
23	2525	460	160	77	47	29	20	14	10	7.8	6.2	5.0	4.1	3.4	2.8	2.4	2.1	1.8	1.6	1.4	1.2	1.1								
24	2800	493	180	88	50	32	22	16	12	8.9	7.6	5.7	4.6	3.8	3.2	2.9	2.4	2.1	1.8	1.6	1.3	1.2	1.1							
25	3060	543	202	97	55	35	24	17	13	10	8.0	6.4	5.2	4.2	3.5	3.1	2.6	2.2	2.0	1.7	1.5	1.3	1.2	1.1						
26	3425	590	219	108	62	39	27	19	14	11	8.6	6.9	5.7	4.7	4.0	3.4	2.9	2.5	2.2	1.9	1.7	1.5	1.3	1.2	1.1					
27	3738	677	243	121	68	43	29	21	15	12	9.6	7.5	6.1	5.1	4.3	3.6	3.1	2.7	2.4	2.1	1.9	1.6	1.5	1.3	1.2	1.1				
28	4100	725	265	129	74	48	32	23	17	13	10	8.3	6.8	5.7	4.8	4.1	3.5	3.0	2.6	2.3	2.1	1.8	1.6	1.5	1.3	1.2	1.1			
29	4440	800	289	141	79	52	35	25	19	14	11	9.1	7.5	6.2	5.2	4.4	3.8	3.3	2.9	2.5	2.2	2.0	1.8	1.6	1.4	1.3	1.2	1.1		
30	4898	864	315	151	88	56	38	28	20	16	12	9.9	8.0	6.7	5.7	4.7	4.1	3.6	3.0	2.6	2.4	2.2	1.9	1.7	1.5	1.4	1.3	1.2	1.1	
31	5312	920	344	168	96	59	40	30	22	17	13	10	8.9	7.4	6.1	5.1	4.5	3.9	3.4	3.0	2.7	2.4	2.1	1.9	1.7	1.5	1.4	1.3	1.2	1.1
32	5631	1070	374	184	103	63	42	32	23	18	14	11	9.3	8.0	6.5	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.6	1.5	1.4	1.3	1.1
33	6154	1140	401	196	109	70	45	35	25	19	15	12	10	8.5	7.1	6.0	5.2	4.4	3.9	3.5	3.0	2.7	2.4	2.2	2.0	1.8	1.6	1.5	1.3	1.2
34	6675	1208	433	212	119	76	51	37	27	21	16	13	11	9.1	7.6	6.4	5.5	4.8	4.2	3.7	3.3	2.9	2.6	2.4	2.1	1.9	1.7	1.6	1.5	1.3
35	7075	1280	470	229	127	82	56	40	30	23	18	14	12	10	8.4	7.1	6.1	5.3	4.6	4.0	3.5	3.1	2.8	2.5	2.3	2.1	1.9	1.7	1.5	1.4
36	7735	1355	497	242	138	88	60	43	32	25	19	16	13	11	8.9	7.6	6.5	5.7	5.0	4.3	3.7	3.4	3.0	2.7	2.4	2.2	2.0	1.9	1.7	1.6
37	8265	1435	537	260	146	94	64	45	33	26	20	16	13	11	9.3	7.9	6.9	6.0	5.3	4.6	4.0	3.6	3.2	2.9	2.6	2.3	2.1	1.9	1.8	1.6
38	8715	1625	575	279	157	100	68	49	37	29	22	18	14	12	10	8.6	7.4	6.3	5.5	4.8	4.3	3.8	3.4	3.1	2.8	2.5	2.3	2.1	1.9	1.8

use 4 times the resistance. By trial it is fairly easy to proportion the system so that the friction is well within 75% of the total available head. Due to the uncertainty of gravity ventilating systems and the expense of installation, they are becoming less and less used. With the cheap cost of electric power and its universal availability for operating fans and motors, positive results and greater satisfaction are assured by their use. Except in the case of small residences, gravity ventilation has little to recommend it.

Tables 26 and 27 will prove useful in checking the flow and friction for hot air furnace installations and all cases where movement by gravity in ducts is involved (see previous examples).

TABLE 26.—AVAILABLE HEAD FOR FLUES OF GIVEN HEIGHT AND TEMPERATURE DIFFERENCE[1] (lb. per sq. ft.)

Height (ft.)	Pressure in pounds per sq. ft. difference in temperature for flues—outside or entering air									
	20 deg.	30 deg.	40 deg.	50 deg.	60 deg.	70 deg.	80 deg.	90 deg.	100 deg.	150 deg.
100	0.27	0.40	0.52	0.65	0.75	0.87	0.99	1.1	1.2	1.7
90	0.25	0.36	0.47	0.57	0.68	0.79	0.89	0.99	1.1	1.5
80	0.22	0.32	0.42	0.52	0.61	0.69	0.78	0.86	0.95	1.3
70	0.19	0.27	0.36	0.45	0.54	0.61	0.68	0.76	0.83	1.15
60	0.16	0.24	0.31	0.37	0.45	0.52	0.59	0.65	0.7	1.00
50	0.135	0.2	0.26	0.32	0.37	0.43	0.49	0.55	0.6	0.82
40	0.11	0.16	0.22	0.255	0.3	0.35	0.38	0.43	0.47	0.66
30	0.0825	0.12	0.16	0.2	0.22	0.26	0.29	0.32	0.35	0.50
20	0.055	0.08	0.107	0.13	0.15	0.17	0.2	0.22	0.24	0.33
10	0.027	0.04	0.052	0.065	0.075	0.087	0.098	0.11	0.12	0.17
5	.....	0.02	0.0255	0.032	0.037	0.043	0.05	0.055	0.06	0.082
3	.....	....	.....	0.019	0.022	0.026	0.029	0.032	0.035	0.05

[1] From "Mechanics of Heating and Ventilation" by Conrad Meier.

28d. Duct and Fan Circulation.—Using the heat loss in Fig. 7 and Table 13, 1,233,000 B.t.u. per hr. for −10 deg. F. outside and 70 deg. F. in the room, determine the sizes for heater and duct system, with Diagram 7 and accompanying tables.

The entering air temperature will be assumed at 120 deg. F. or 50 deg. above the room temperature with 10 deg. lost in the ducts. The total heat required will be $\frac{1{,}233{,}000 \times 140}{50} = 3{,}450{,}000$ B.t.u. per hr.

The air required will be

$$\frac{\text{B.t.u. per hr.}}{60 \text{ min.} \times \text{diff.} \times \text{spec. heat of air} \times W \text{ at } 70 \text{ deg. F.}} = \frac{3{,}450{,}000}{60 \times 140 \times 0.24 \times 0.075} = \frac{3{,}450{,}000}{151.2} = 22{,}820 \text{ cu. ft. per min.}$$

If all out door air were used, this would have to be raised from −10 deg. F. to 130 or 140 deg. F.

In extreme weather it is customary to recirculate part of the air say ½, from the room at 70 deg. F. and the remainder from out of doors. This arrangement is accomplished by means of dampers. If the air is recirculated, the rise in temperature will be ½ the air from 70 deg. F. and ½ from −10 deg. F., or the entering temperature of the mixture will be 30 deg. F., average.

Assuming for this case 5-lb. steam pressure in the coil or 227 deg. F. and a velocity of 1200 ft. per min. through the clear area of the heater, we have $\frac{22{,}820}{1200}$ 19.02 sq. ft. free area.

From the tables in the manufacturers' catalogs, a pipe coil may be selected with $f' = 17.1$ sq. ft. of heating surface per sq. ft. free area. The number of stacks of pipe coils deep required can be calculated from Formula 7, p. 1122.

$$\text{Log} \frac{\theta_s - \theta_1}{\theta_s - \theta_2} = \frac{f'N}{0.1118V + 127}$$

TABLE 27.—FRICTION, AREAS OF SQUARE FLUES, AND DISCHARGE IN CU. FT. PER MIN. FOR SQUARE DUCTS FOR USE IN GRAVITY VENTILATION[1]

Pressure drop (lb. per sq. ft. per 10-ft. length)	Areas of ducts in square feet																
	0.5	0.8	1	1.5	2	2.5	3	4	5	6	7	8	9	10	12	15	20	25
0.03	240	450	600	1020	1500	1980	2550	3720	4980	6240	7800	9000	10800	12100	15600	21000		
0.02	204	360	492	840	1200	1620	2070	3000	4020	5040	6240	8100	8100	10200	12600	16800		
0.015	168	315	420	720	1050	1410	1770	2580	3540	4380	5400	6C00	7800	8520	10800	14400	20000	28500
0.01	141	252	336	570	870	1140	1470	2070	2760	3540	4320	5220	6000	6900	8700	11700	16800	22800
0.009	132	240	324	540	810	1050	1380	2010	2640	3360	4080	4920	5700	6720	8100	11100	16200	21600
0.008	120	225	300	510	774	1020	1260	1860	2520	3150	3840	4620	5280	6120	7800	10620	15600	20700
0.007	111	210	276	474	720	924	1178	1680	2310	2880	3570	4320	4980	5760	7200	9780	14400	19200
0.006	107	192	255	432	648	858	1104	1600	2130	2700	3300	4020	4620	5280	6720	8880	13200	17100
0.005	99	174	234	396	582	798	1002	1440	1980	2460	3000	3600	4200	4800	6000	8400	11880	15600
0.004	84	156	210	354	516	700	882	1260	1710	2190	2640	3240	3720	4260	5400	7200	10800	14400
0.003	72	144	180	300	444	588	780	1098	1470	1920	2280	2790	3210	3660	4656	6180	9000	12000
0.002	58	108	144	240	360	480	606	834	1200	1500	1890	2220	2580	2940	3720	5040	7380	9780
0.0015	50	91	126	210	318	408	522	774	1032	1290	1590	1968	2190	2520	3210	4290	6360	8400
0.001	40	75	102	171	252	330	420	612	834	1056	1260	1560	1770	2040	2580	3180	5100	6900
0.0008	36	67	90	150	220	294	381	540	740	924	1140	1410	1620	1800	2280	3120	4500	6000
0.0006	31	57	76	130	192	260	327	468	636	792	1000	1180	1380	1600	1980	2670	3840	5160

[1] From "Mechanics of Heating and Ventilation" by Conrad Meier.
Factor for round pipes = 0.87

Factors for rectangular shapes: $1 \times 2 = 1.07$; $1 \times 3 = 1.18$; $1 \times 4 = 1.3$; $1 \times 5 = 1.43$

$$\text{Velocity} = \frac{\text{Discharge per minute}}{\text{Area at top of column}}$$

where f' is the square feet of heating surface per square foot of free area for one stack. These initial and final temperatures are given in all manufacturers' catalogues. Utilizing the above formula and substituting proper values in the above equation.

$$\text{Log}\ \frac{227\ \text{deg.} - -10\ \text{deg.}}{227 - 130} = \frac{17.1\ N}{(0.1118 \times 1200) + 127}$$

$$N = \frac{\text{Log}\ 2.4433}{0.0654} = \frac{0.3879768}{0.0655} = 5.93 \text{ stacks of pipe coils deep, or } 6.$$

If the air is recirculated in extreme weather, which is advisable due to expense of steam or fuel when the outside temperature is about 10 deg. F. above zero, the number of sections required would be:

$$\text{Log}\ \frac{(227 - 70)}{(227 - 130)} = \frac{\text{Log}\ 1.6186}{0.0655} = \frac{0.2091395}{0.0655} = 3.2 \text{ or 4 stacks deep.}$$

Put in 4 stacks and recirculate or raise the steam pressure when below 10 deg. F., or recirculate a portion of the air in extreme weather.

The total heating surface of the stack is $6 \times 17.1 \times 19.02 = 1950$ sq. ft. surface.

The friction through the heater will be that due to a velocity of 1200 ft. per min. The condensation at 5-lb. pressure will be, with air at −10 deg. F., measured at 70 deg. F. $\frac{3,450,000}{961} = 3590$ lb. steam per hr. If ½ the air is recirculated in 10 deg. F. weather, the rise in temperature will be $\frac{70 + -10}{2} = 30$ deg. The condensation will then be for a difference in temperature of 130 deg. −30 deg. = 100 deg., or $\frac{100}{140} \times 3590 = 2564$ lb. per hr. If all

the air is recirculated, the rise in temperature will be 130 deg. −70 deg. = 60 deg., and the condensation will be 2564 × 0.6 = 1540.0 lb. steam.

Using Diagram 6, we have θ'_s = 227 deg. F., θ_1 = −10 deg. F.; θ_2 = 130 deg. F., $\theta'_s - \theta_2$ = 97 deg. F., $\theta_s - \theta_1$ = 237 deg. F. Select the abscissa on the middle chart and move up to curve $\theta_s - \theta_2$ = 97 deg. F., select the ordinate at this intersection and move to the right to the curves for 1200-ft. per min., velocity which gives f for pipe coils = 102.5 and for Vento = 115. This ordinate is the one next to the heavy line illustrating a previous problem.

Using a coil with f = 17.1 sq. ft. per sq. ft., the number of stacks of 4 row sections deep is $\frac{102.5}{17.1}$ = 6 deep or 24 rows of pipes, which checks with the analytical work. Total surface = 19 sq. ft. × 6 × 17.1 = 1950 sq. ft. Moving on the same ordinate to the left to curves for $\theta_2 - \theta_1$ = 140 deg. F. and moving up the abscissa at this intersection, we have $\theta_s - \theta_m$ = 157 deg. F., and from Diagram 5 we have k for pipe coils = 11.4 B.t.u.

1950 × 157 deg. × 11.4 = 3,490,000 B.t.u.

In case a Vento section is used, select from Table 20 the regular section, 5⅜-in. centers, f' = 14.6, 72-in. height, 1.303 sq. ft. free area per section.

$$\frac{115}{14.6} = 8 \text{ stacks deep}$$

$$\frac{19.02 \text{ sq. ft. total free area}}{1.303 \text{ sq. ft. free area per section}} = 15 \text{ sections.}$$

15 sections, 8 deep × 19 sq. ft. = 2280 sq. ft. of heating surface.

From Diagram 5, using cast-iron Vento with 1200-ft. per min. velocity, and $\theta_s - \theta_m$ = 155 deg. F., 155 deg. × 10.2 B.t.u. × 2280 sq. ft. = 3,605,780 B.t.u. By selecting a section with the correct factor f, or changing the velocity, the most economical section may be selected.

Assuming the condition of one-half the entering air recirculated or an average entering temperature, θ_1 = 30 deg. F., θ_s = 227 deg. F., θ_2 = 130 deg. F., $\theta_s - \theta_1$ = 197 deg. F., $\theta_s - \theta_2$ = 97 deg. F., and $\theta_2 - \theta_1$ = 100 deg. F. Selecting Diagram 6 as before, $\theta_s = \theta_1$ = 197 deg. F. and curve $\theta_s - \theta_2$ = 97 deg. F., we have f for the Vento = 90 and for pipe coils = 80. $\theta_s - \theta_n$ for both is 140 deg. F., using curve $\theta_2 - \theta_1$ = 100 deg. F., and the same ordinate.

Pipe coils will require, if f' is 19.6 (Table 23), $\frac{80}{19.6}$ = 4.1 sections deep, say 4 sections, with slightly higher velocity or greater area. The square feet of heating surface or 19.02 sq. ft. free area = 19.6 × 19.02 × 4 = 1489.6 sq. ft. in the coil, 4 sections, 4 pipe deep. Then 1500 sq. ft. × 11.4 B.t.u. (Diagram 5) × 140 deg. = 2,394,000 B.t.u. per hr. $\frac{2,394,000}{961 \text{ B.t.u.}}$ = 2500 lb., which checks with previous analytical work.

Assuming 50-in. Vento, f' = 14.92, 5⅜-in. centers, 0.905 sq. ft. free area per section, and 13.5 sq. ft. surface per section, we have (Table 20) $\frac{90}{14.92}$ = 6 sections deep.

$$\frac{19.02 \text{ total sq. ft. free area}}{0.905 \text{ sq. ft. free area per section}} = 21 \text{ sections}$$

21 sections × 6 × 13.5 = 1700 sq. ft. of heating surface in the stack.

Diagram 5 gives 10.4 B.t.u. for 1200 ft. velocity.

$$\frac{2,475,200}{961 \text{ B.t.u.}} = 2576 \text{ lb. steam per hr., which also checks.}$$

Diagrams 5 and 6 will enable any problem in handling air to be solved, either gravity or fan work, if the square feet of surface per square foot of area f' is known. This takes the place of all the voluminous tables in the Vento book and those published by blower companies.

29. Duct Systems.

29a. Trunk Line Ducts.—Fig. 31 shows a layout for trunk-line duct with 30 outlets with a capacity of 1000 cu. ft. for each outlet. We will allow the lowest velocity at 1000 ft. per min. for the longest line of 210 ft. Diagram 8 gives for 2000 cu. ft. (for the 2 outlets on this line) a 20-in. round duct and 0.09 in. friction per 100 ft. For all branch ducts, use 0.09 in. per 100 ft. and for the main trunk use 0.1. In using chart, follow up the 0.1-in. line until it intersects at right angles the discharge, and the nearest velocity and size pipe to this intersection will be the proper ones to select. Referring to letters on Fig. 31, Table 28 gives the resulting readings. The duct lines are sized for practically the same drop per 100-ft. run and the velocities at the outlet are regulated by volume dampers set at the proper point. The opening of the nearby dampers will be much less than those at the end of the line. These are set with an anemometer after installation as the pressure near the fan is much greater than at the remote parts of the system. Flaring reducers may be used to reduce the velocity to the same rate for all outlets.

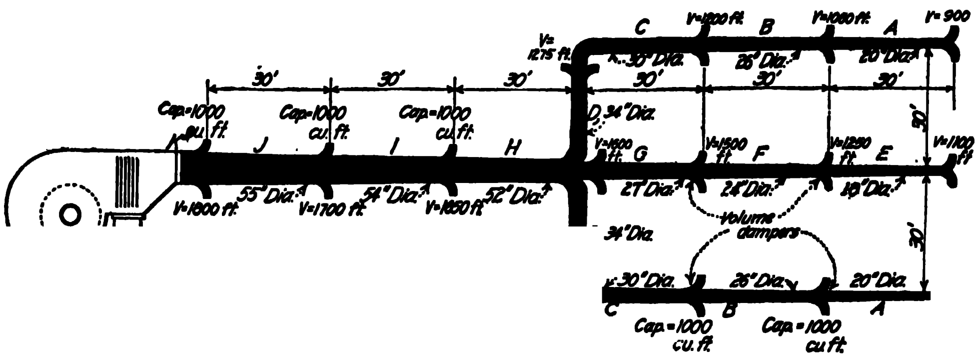


FIG. 31.—Trunk line duct system.

TABLE 28

No.	Capacity (cu. ft. per min.)	Diameter (in.)	Velocity (ft. per min.)	Friction (in. of water per 100 ft.)	Length (ft.)	Friction (in. of water for entire length)	Total friction (in. of water)
K	30,000	56	1,800	0.110	10	0.011	
J	28,000	55	1,700	0.100	30	0.03	
I	26,000	54	1,650	0.0975	30	0.0293	
H	24,000	52	1,600	0.09	30	0.027	
D	8,000	34	1,275	0.09	30	0.027	
C	6,000	30	1,200	0.09	Ell 25 Tee 30	0.0495	
B	4,000	26	1,060	0.085	30	0.0255	
A	2,000	20	900	0.075	30	0.0225	0.2218
KJIH	.....	..	....	....	..	0.0073	
E	2,000	18	1,100	0.13	30	0.039	
F	4,000	24	1,250	0.13	30	0.039	
G	6,000	27	1,500	0.15	30	0.045	0.2203

The total drop in friction K, J, I, H, D, C, B, A (Table 28) 0.2218

The friction through the heater 6 sections, 1200 ft. velocity, Table 23 gives ABC coil @ 1000 ft.—24 pipes 0.186 in. water $0.186 \times (1.2)^2$ in. water 0.268

Velocity head 1800 ft. per min. or 30 ft. per sec. $\frac{900}{4455.6} =$ 0.2

Allow 50% duct loss for obstructions 0.11

Total .... 0.7998 in. water

A pressure head of 1.25 in. water on fan will be ample. The horsepower of the fan will be as follows:

Let H = head in inches of water = 1.25 in.

Q = cu. ft. of air at 70 deg. F. per min. = 30,000 cu. ft.

33,000 ft.-lb. = 1 hp. $\text{hp.} = \frac{5.2HQ}{33,000}$

In such calculation take fan efficiency at 50% although it may run from 40 to 60%.

$$\text{hp.} = \frac{5.2 \times 30,000 \times 1.25 \text{ in.}}{33,000 \times 0.5} = 12 \text{ hp., or say 15-hp. motor.}$$

29b. Separate Ducts.—Fig. 32 is a layout for separate ducts for each flue or room. In this case there will be the same drop in the total length of each duct, varying the area and velocity to accomplish this, rather than, as in the former case, having nearly the same

drop per unit of length. Also, it is desirable to use rectangular ducts so that they will lie close together. We will make H and K double the depth, or 24 in., while the others will be 12 in.

Using Diagram 8 as before and 0.21 in. for the total drop in each duct, we have

TABLE 29

No. of outlet	No. register outlets	Capacity of outlet (cu. ft.)	Total capacity (cu. ft. per min.)	Length of pipe (feet)	Drop per 100 ft. $\frac{0.21 \times 100}{l}$ (in. of water)	Diameter of pipe (in.)	Velocity (ft. per min.)	Size rectangular pipe $D = \frac{4 \times A \times B}{2(A+B)}$ (in.)
A	2	1000	2000	10	2.10	8	1800	6 × 12
B	2	1000	2000	40	0.52	10½	1700	10 × 12
C	2	1000	2000	70	0.3	11½	1400	12 × 12
D	2	1000	2000	100	0.21	12½	1200	14 × 12
I.E.	6	1000	6000	130	0.161	13	1100	15 × 12
J.F.	6	1000	6000	160	0.131	14	1000	16 × 12
G	4	1000	4000	190	0.111	14½	950	18 × 12
K	1	2000	2000	190	0.111	18½	1050	15 × 24
H	2	2000	4000	220	0.0955	19	1000	16 × 24

The total drop in the above system will be the same as for Fig. 31. This system is often used in schools and especially where tempered air at 70 deg. F. and higher is desired for combined heating and ventilation. The desired temperature is obtained by the use of thermostatically controlled mixing dampers.

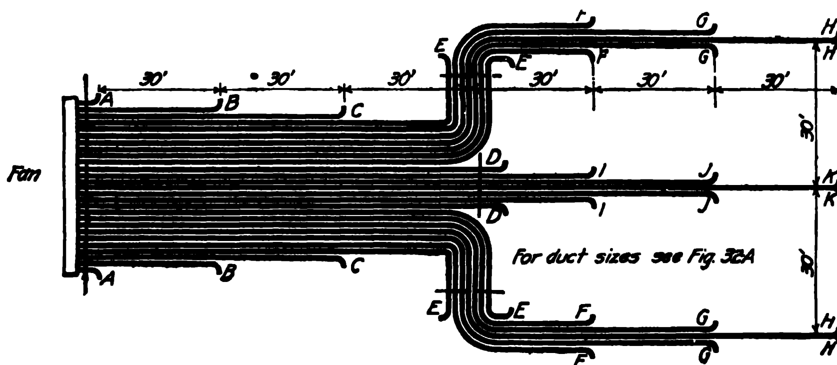


FIG. 32.—Separate duct system.

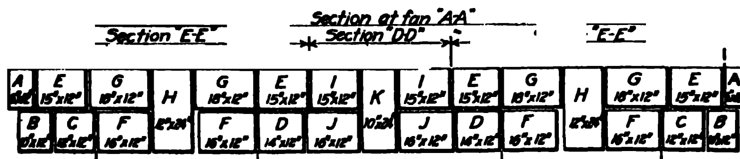


FIG. 32A.—Cross section through separate duct system (Fig. 32).

It often occurs where the ventilating system is combined with the heating system, as in schools or auditoriums, that the heat carried by the air necessary for ventilation will be more than enough to produce the proper temperature, in such cases, the B.t.u. losses should be divided into the amount of air required for ventilation to obtain the proper rise in temperature. If the B.t.u. loss is 1,600,000 and there are 2000 people requiring 30 cu. ft. of air per min. for ventilation, then the diffusion or heat required above the normal room temperature to replace the heat losses will be

$$\text{Diffusion} = \frac{1{,}600{,}000 \text{ B.t.u.}}{2000 \times 30 \times 0.075 \times 0.24 \times 60} = \frac{1{,}600{,}000}{648{,}000} = 2.63 \text{ deg. to replace the heat losses.}$$

It the air for ventilation is raised to 3 to 5 deg. above the room temperature, it will be sufficient for warming. This will give an entering temperature of 73 to 75 deg. F. The heater must be designed by the same method as before but with greater area and less rise in temperature.

As a general rule, ventilating system should not be combined with the heating system. Separate heating systems should be provided, in addition to the ventilating system, for the sake of economy.

30. Fans and Blowers.—Power fans should be used for all ventilation. Such equipment can be obtained in a variety of forms, convenient and economical to operate. There are several types of fans, each having its characteristics.

Disk fans, which are used for ventilation, will remove the air from a room or supply air for any purpose where large volumes are desired at low resistances. It is not economical to operate them on a duct system against any appreciable resistance. The "Ventura" fan and the "Blackman" fan are built up to 10 or 12 ft. in diameter and make excellent exhaust fans. Cone fans will produce considerable pressure and they need no housing.

The old type of paddle wheel fan is built by all fan manufacturers. The width is about ½ the diameter and the wheel diameters are generally from 2 to 16 ft. The housings come the same as for other fans, with various arrangements for the outlets and inlets. They are excellent where a slow speed is desired, as when operated by an engine, although they take up a great deal of space.

In selecting fans the important points to look for are to see that they are perfectly balanced and have oil wells with ring bearings. The speed should not be over a mile a minute for the periphery of the wheel. At speeds higher than this any fan is apt to be noisy.

Multiblade Fans.—This type has a very large inlet nearly the full diameter of the wheel, with a series of narrow blades set close together in the rim. They are coming quite generally into favor due to the small space required for a given capacity as compared with the paddle wheel type.

This type of fan was introduced by John Davidson of Belfast, Ireland, and exploited by the American Blower Company. Other companies followed and varied the design for selling purposes. They are known as the "Sirroco," Multivane, Conoidal, Plexiform, and others, depending on the company selling them.

These fans are well adapted for high speed prime movers, such as turbines or motors. For large capacities they are built double width with two inlets, requiring a small space and diameter with low headroom.

All fan manufacturers issue detailed information concerning their product. Fan problems should be taken up with these companies direct, as limited space prevents a more extended treatment of the subject. Multivane fans have different characteristics peculiar to each type manufactured.

Attention should be called to the use of disc ventilating fans in connection with long vertical flues for exhausting air. The capacity of the flue under natural draft should be determined first, as in many cases the velocity from natural draft, due to height, is such that the fan and motor add nothing but actually reduce the capacity. In all cases requiring pressure and positive action against resistance the multivane type is the one to use. More positive action is also obtained by driving the air through a duct system than by exhausting it, that is, placing the duct system on the discharge of the fan rather than on the suction side.

31. Allowance for Fittings.—Tables 30 and 31 give the corrections for elbows and fittings for steam, water, and air. The writer generally allows for these in the total head as they occur on all circuits in about like proportion. Due to the fact that construction may not be in accordance with the calculated assumption and these calculations are, at best, not accurate, the writer believes it better to allow in the total available head for friction in elbows and other fittings. Steam and water fittings have a great resistance when reducing on the run and these can be avoided in most cases in designing. With long turn ells on large sizes, in case of water, the losses are minimized. The table is given in case it is desired to include them in this class of work.

TABLE 30.—RESISTANCE OF 90-DEG. ELBOWS

Radius of throat of elbow in diameters of pipe	¼	½	¾	1	1¼	1½	1¾	2	2½	3	3½	4	4½	5	5½
Number of diameters of straight pipe offering equivalent resistance	67.0	30.0	16.0	10.0	7.5	6.0	5.0	4.3	4.5	4.8	5 0	5.2	5.5	5.8	6.0

TABLE 31.—EQUIVALENT LENGTH OF STRAIGHT PIPE FOR FITTINGS AND VALVES

Size of pipe (inches)	1	1¼	1½	2	2½	3	3½	4	5	6	7	8	10
Steam ell	1.5	3	3.5	5.0	6	9	11	13	19.0	24.0	29	35	41.0
Globe valve	2.0	4	5.0	7.0	10	14	17	24	37.0	44.0	53	61	78.0
Gravity water	2.0	3	3.5	4.5	6	7	9	10	14.5	17.5	19	21	26.5

Note.—Long turn ells should be used on all steam and water on the larger sizes. Gate valves should be used instead of globe valves. Reducing fittings should be avoided on the run. High pressure steam does not matter as slight increases of pressure will obviate the matter and the maximum load is seldom carried.

BOILERS, FUELS, AND CHIMNEYS

32. Types of Boilers.—The different types of boilers may be classed as follows:

(1) Water tube

(2) Fire tube
- a. Internally fired
  - Scotch Marine
  - Locomotive
  - Fire box boilers
- b. Externally fired
  - Horizontal tubular

(3) Sectional (Cast iron)
- a. Round
- b. Sectional
- c. Watertube

The boiler proper is the heat absorbing surface interposed in the passage between the grate and the chimney to absorb the heat from the hot gases produced by the combustion of the fuel. Its function is separate and distinct from the combustion system composing the grate and chimney.

33. Requirements of a Perfect Boiler.—The writer cannot improve on G. H. Babcock's requirements for a perfect boiler published in *Steam* and they are just as true today as ever. They are as follows:

(1) Proper workmanship, simple construction, and using materials which experience has shown to be the best.

(2) A mud drum removed from the action of the fire to receive all impurities deposited from the water.

(3) A steam and water capacity sufficient to prevent any fluctuation in steam pressure or water level.

(4) Water surface for the disengagement of the steam from the water, or sufficient extent to prevent foaming and priming.

(5) A constant and thorough circulation of the water throughout the boiler so as to maintain all parts as near the same temperature as possible.

(6) Water space divided into sections so arranged that should any section fail, no general explosion will occur and the destructive effects will be confined to the escape of the contents. Large and free passages between the different sections to equalize the water line and pressure in all.

(7) A great excess of strength over any legitimate strain, the boiler being so constructed as to be free from unequal expansion strain and, if possible, to avoid all joints exposed to the direct action of the fire.

(8) Have the combustion chamber so arranged that the combustion of the gases started in the furnace shall be completed before escaping to the chimney.

(9) The heating surface as nearly as possible at right angles to the currents of heated gases so as to break up the currents and extract the entire available heat.

(10) All parts readily accessible for cleaning and repairs both inside and outside. This is of the greatest importance.

(11) Proportioned for the work and capable of working to the full capacity with the highest economy.

(12) Equipped with the very best trimmings, gages, safety valves, and fixtures, not forgetting instruments of precision in order to determine the record of performance.

(13) Straight tubes are better than curved tubes both in cleaning and replacements as curved tubes are sometimes hard to obtain in an emergency.

34. Heating Surface.—The heating surfaces are classed as (1) direct fire surface or that exposed to the direct rays of the fire, absorbing heat both by radiation and convection; (2)

indirect surface or that which absorbs heat by convection only, and (3) superheating surface; or that which has steam instead of water on one side. The average absorption of power boilers is from 2000 to 3000 B.t.u. per sq. ft. of heating surface per hr. The American Radiator Company claims an absorption of 10 B.t.u. per sq. ft. per deg. difference for direct heating surface and for indirect or flue surface for a difference in temperature of from 800 to 900 deg. between the water and gases, 3.5 B.t.u. per sq. ft. per deg.

This means that the direct fire surface has a greater value by 4 or 5 to 1 than flue surface in a boiler. At the same time, these higher temperatures require a more intense fire and greater attention.

35. Water-tube Boilers.—These are used where large units are required to economize space and obtain high rates of combustion in order to carry heavy overloads as well as a wide range of power load, thus reducing the number of boilers and fires. Most of them are composed of small cylindrical units with thin walls, capable of withstanding high pressures. All are sold and rated on 10 sq. ft. of heating surface per horsepower. The heating surface being in tubular and cylindrical forms, is fairly easy to check. Nearly all water-tube boilers require brick settings, and are erected in sections so that they may be taken into buildings through small openings.

36. Fire-tube Boilers.—As the name indicates, the heating surface of these boilers consists of tubes surrounded by water and through which the hot gases pass and are known as internally and externally fired.

The Locomotive and Scotch Marine are the most common types of internally fired boilers, while the horizontal tubular is externally fired. The locomotive type has a fire box formed of the extension of the shell or barrel containing the tubes. The sides and top of the fire box are annular and require careful staying due to the fact that the surfaces are flat and will not withstand pressure like cylindrical sections. They are short lived where bad water is used due to collection of scale on surfaces exposed to the fire. The type used for stationary heating practice is called a fire box boiler.

The Scotch Marine boiler consists of a large cylinder with corrugated circular fire boxes passing from head to head, the grates setting in the lower portion of the fire box It may be built from 8 to 20 ft. in outside diameter and sometimes has 3 fire boxes. It may also be arranged to be fired from both ends. The circulation of the water under the corrugated fire boxes is poor due to the dead space under the fire except when on a ship at sea. On land the circulation is remedied by using a small pump to circulate th · water from the bottom to the top. No brick work is required, and the fire, ash pit, etc., are all surrounded by heating surface and water. The shell, however, needs to be well insulated. Combustion arches are sometimes used of masonry to aid combustion.

The horizontal tubular boiler is the most common type of boiler used in stationary practice. It is a simple shell partially filled with tubes set in brick work and is one of the most reliable, and when well set will equal any boiler in economy. All shell boilers are limited as to pressures and capacity by the diameter and thickness of shell exposed to the fire. The riveting of the shell and bracing of the heads are important details of construction.

The Hartford Steam Boiler and Inspection Company furnishes specifications and details of the best practice in the setting and construction of these boilers. Care must be exercised that sufficient entrance space is always provided for erection in buildings.

37. Settings.—Boilers should be set with hard brick with lime mortar. Little cement is used due to the possibility of cracking. Furnaces and sides up to the lugs should be lined with fire brick set in fire clay. A slow fire should be started and kept going until the setting is thoroughly dry to avoid cracking. The top may be covered with a course of brick or pipe covering.

In the past domes were provided to furnish dry steam but due to weakening the shell, they are generally omitted and dry pipes furnished.

Proper foundation should be placed under the walls with a sufficient thickness and spread to carry the boiler without settling. Buck stays and tie rods are used to hold the side walls in place and keep them from spreading but they should never be used longitudinally. The boilers are supported in two ways: (1) directly on the walls by means of lugs riveted to the shell resting on the brick walls, and (2) by means of 4 steel columns, one at each corner of the setting, supporting a steel beam from which one or more boilers may be suspended with suspension rods riveted to eye bolts on each side of the shell. By this method of suspension the boilers are supported entirely independent of the brick setting. With the lug method, two lugs are used on each side, resting on plates on the brick work, the rear lug have bearing rolls so as to provide for expansion.

Settings may be found in all boiler manufacturers' catalogues.

38. Area of Grate.—The rate of coal consumption per square foot of grate may be anything for which the combustion system is designed by taking the maximum power load in horsepower and reducing it to terms of fuel per hour. From 10 to 25 lb. of soft coal may be burned per sq.

ft. of grate per hour. Horizontal tubular boilers generally have a grate surface equal to the square of the diameter of the shell. This is often lengthened a foot or two where a slow rate of combustion for heating purposes is desired, for coal capacity and to reduce periods between firings, or for purposes of operating at overloads.

39. Rating.—The 36 to 42-in. boilers are rated at 12 sq. ft. of heating surface per horsepower and all above that at 10 sq. ft. They are built in units up to 355 hp. with 96-in. shells 22 ft. long. To reduce the ratings to standard square feet of steam radiation, multiply by $\frac{\text{hp.} \times 34\ 5\ \text{lb.}}{0.25}$. It would be advisable when smaller sized fire-box boilers are used under low pressure for heating purposes, to increase the heating surface per horsepower to 12 and 15 These catalogue ratings are simply a measure of the amount of boiler or heating surface being purchased, for both buyer and seller are equally able to check the size and heating surface. They have little to do with the rating under which the boiler may ultimately be operated in actual service. The heating surface per horsepower increases as the load decreases. Thus, if a boiler were operated under 60% of its rating in service, the square feet of surface per horsepower would be, if 12 sq. ft. were the standard at full load, 20 sq.-ft. of heating surface per horsepower.

Any power boilers may be used for gravity or forced hot water circulation, and the water may be circulated directly through it. In the case of forced hot water circulation, the velocity of the water over the surface enables it to be reduced to about 6 sq. ft. of heating surface per hp. of work. In some cases the shells of horizontal tubular boilers have been completely filled with tubes for this purpose. This is of no advantage and makes the boiler inaccessible for inspection and the added tube heating surface is inefficient.

Indetermining the size of a power boiler, multiply the B.t.u. loss by 1.3 and divide by 33,500 B.t.u. to obtain the boiler horsepower, and use 12 sq. ft. of heating surface per horsepower for small sizes and 10 for large.

40. Cast-iron Boilers.—Cast-iron boilers are built in sections so as to go into inaccessible places and through small passages. This method of construction makes the labor of erection and handling less. They are built round and square, the sections being connected with push nipples or screwed nipples with headers and lock nut joints. The general proportions are ⅔ direct fire surface and ⅓ flue surface due to the draft resistance on low chimneys. The area of grate should be checked, and with the distance to the center of the fire door to the grate the possible fuel charge may be determined. Where low chimneys are used, the boiler selected should have as little flue surface as possible. Where a higher chimney is available, the flue surface will be of advantage. It is almost impossible to tell anything about the ratings and capacities of cast-iron boilers from the catalogues as the heating surface or the draft resistance are not given. One simply has to take the manufacturer's word for the size and trust to experience.

It is possible by proper firing on house heating boilers to burn soft coal with little smoke. If the fuel is fired at the front of the furnace and allowed to coke, as the distilled gases pass over the incandescent fuel bed at the rear, good results may be obtained.

The American Radiator Company and Hart and Crouse (Royal) use the Hawley down draft which is composed of an upper water grate. The former uses cast iron and the latter uses a grid of extra heavy wrought-iron pipe on which the green fuel is fired. The upper fire door is left open to supply the air which passes down through the green fuel bed to the bed of coked coal on the lower grate. This lower fire distills the coal above and consumes the gases. After the coal is coked on the upper grate it is pushed or falls to the lower where combustion is completed. These boilers need greater intensity of draft than ordinary types and the construction of the water grate should be such that expansion strains are avoided, as these create leaks.

The H. B. Smith and U. S. Radiator Corporation use a form of combustion arch for smokeless boilers. Both these principles are well known and are efficient. These types of boilers are being used on some of the largest buildings up to 40,000 and 50,000 sq. ft. capacity. The down draft furnace is used on any type of power boiler but stokers and forced.draft are more usual for they give greater capacity and at the same time smokeless combustion.

The necessities of the situation demand that heating boilers under 2000 sq. ft. of radiation be operated under a wide range of load with long periods (8 to 10 hr.) between firings thus engendering low flue temperatures and poor combustions. Under conditions of low flue temperatures, the fuel distills off with incomplete combustion, but with higher flue temperatures induced by a higher combustion rate, the products of distillation are consumed and more than make up for the loss engendered by the higher flue temperature.

The higher flue temperatures and improved draft increase the capacity of the same boiler due to greater transmission rates and increased velocity of the gases. Most boiler manufacturers recommend an increase of 25 to 100 % in the square feet of radiation installed when selecting a boiler by catalogue ratings, ascribing the reason

to uncovered mains, etc. For reasons already given, the square feet of radiation should never be used for the determination of the maximum boiler load although there is no objection to dividing the total B.t.u. load, as determined, by 250 B.t.u. to reduce it to the unit of rating in manufacturers' catalogues.

These increases should be made, but for entirely different reasons, as follows:

1. The calculations for heat loss and radiation are on a basis of supplying the heat only to keep the room at 70 deg. F. with zero or −10 deg. F. outside. In case the room drops to 60 deg. F. with zero weather outside, the building loss is reduced while the radiation transmission is increased, and all the mass of the building, furniture, etc., has to be raised to 70 deg. F. before the thermometer will register that temperature.

2. In addition, if the radiation is cold, all iron and water in the system has to be raised to the working temperature, say 210 deg. F. A certain portion of this heat has to be furnished every time the radiators are turned off and although not lost, it is given out at such times as to be of little use for actual heating. This is an explanation of the excessive fuel when intermittent heating is practiced on a large plant.

3. The time in which these losses can be supplied is dependent on the boiler capacity. The larger the boiler, the shorter the time, irrespective of the type of heating system.

Assume the data of a previous problem with 1,239,000 B.t.u. per hr., and 5500 sq. ft. of radiation, and with a difference of (70 − −10) 80 deg. between the room and the outside. When raising a room temperature, the rise has to be doubled, or if 10 deg. rise is required, the actual work required will be 20 deg., so the heat required to raise it 10 deg. or from 60 to 70 deg. will be $^{20}/_{80} \times 1,239,000 = 310,000$ B.t.u. With 8 lb. of iron per sq. ft. of radiation, and 0.12 as the specific heat of iron, the heat to raise the iron from 60 to 210 deg. will be:

Steam Systems

(1) Iron, 5500 × 8 (lb.) × 0.12 × 150 (deg.) = 792,000 B.t.u.

(2) Increment 10-deg. rise $= \frac{20}{80} = \frac{1}{4}$

(3) Normal heat loss (0° 60°) $= \frac{3}{4}$ } = 1,240,000 B.t.u.

(4) Steam (medium), 5500 × 0.025 (cu. ft.) × 0.04 (spec. vol.) × 1000 = 5500 B.t.u.

Total = 2,037,500 B.t.u = 165% of 1,240,000 B.t.u.

Water System

Items (1), (2), and (3) = 2,032,000 B.t.u.

(4) Water (medium), 5500 × 1.5 (lb.) × 1 × 150 (deg.) = 1,237,500 B.t.u.

Total = 3,269,500 B.t.u. = 266% of 1,240,000 B.t.u.

if it is to be accomplished in one hour. If the work is to be done in 1½ hours, the boiler power required would be 66% of the above items. As zero weather occurs seldom and the building would probably not be allowed to be cooled to too low a temperature at such times, 130 to 150% should be ample if the boiler has the actual capacity represented. It is possible with proper chimney and draft to increase a boiler capacity to any reasonable extent.

Boiler tests show that 500 deg. flue temperature and 6 to 7 sq. ft. of heating surface per boiler horsepower are required for economy of fuel. For a low flue temperature of 300 deg. and long periods between firings, 10 or 12 sq. ft. should be provided. It has already been found that the proper load is 130% of B.t.u. losses. Assuming the cast-iron boiler manufacturer has rated his boiler on 7 sq. ft. per hp. of work, and 10 is needed, we have an increase of 143% in the rating due to lack of heating surfaces.

Let S = radiation in square feet at 250 B.t.u.

then 1.43 × 1.3 = 1.859 × S = catalogue rating of the boiler to be selected. This is about what the manufacturer recommends. See that the chimney is designed for boiler selected and not for the load. This is at best a guess. If the heating surface and draft pressure (flue temperature and height of chimney) is available from the manufacturer, the problem is simplified. Remember these boilers are tested and rated with high flue temperatures, good draft conditions and hard coal that requires minimum draft pressure which give the greatest fuel economy with a minimum of heating surface.

In using cast iron boilers on forced hot water, the static pressure will limit the use of most makes to 40 lb. pressure as the test is 80 lb. The H. B. Smith Co. makes the mills water tube boiler with nearly all direct surface, that will stand 200-lb. test.

41. Boiler Trimmings.—All steam boilers must be provided with steam gage, water column with water gage and try cocks, safety valve, and damper regulator. Water boilers are provided with thermometers and an altitude pressure gage. All power boilers are provided with the same fittings or trimmings but of a different type, generally two safety valves, blow off cocks, low and high water alarm on the water columns' and automatic check and stop valves. These latter automatically shut the boiler off in case of a break in the steam main. All trimmings, grates, and fire tools are furnished with cast-iron boilers.

42. Connecting Two Boilers.—In connecting two or more boilers in a battery for gravity return heating, they should be yoked together with a large equalizing pipe in separate steam outlets independent of other connections. The return should also be connected in like manner,

otherwise the water line of the boilers will vary considerably. Equalizing connections outside of the boiler, between steam main and return main, do no good and sometimes harm.

43. Check Valves. Check valves of swing type should be used on all boiler connections so that water can enter the boiler, but not escape in case of breaks or carelessness in opening valves. They do not, however, assist circulation. If the system circulates unequally without their introduction they will not better conditions. Many steam fitters think a check valve a panacea for all badly designed plants.

44. Feed Pump.—If the duplex plunger pump is large and operated fairly slow with some attention to the needs, it is more economical than the centrifugal pimp. It has this disadvantage that when the valves are all shut on the boilers the pump will place the full pressure on the feed line before stopping. An automatic pump regulator would obviate this.

The centrifugal pump will place a certain head on the main and is fool proof. It also will fall off in power as the gallons are reduced due to curtailment and may be run continuously regardless of the water required. Operated by a steam turbine under back pressure, it will require more steam than the compounds piston pump with a due amount of attention.

45. Equivalent Evaporation.—As boilers are operated at various steam pressures with possibly entrained moisture, their performance cannot be compared by simply determining the number of pounds of water evaporated by each Instead, the performance of each boiler must be reduced to its "equivalent evaporation" from and at 212 deg. and then the boilers may be compared on this common basis. The equivalent evaporation from and at 212 deg. is found by multiplying the number of pounds of water actually evaporated per hour by the "factor of evaporation."

The factor of evaporation is equal to the number of heat units actually supplied by the boiler to each pound of steam, divided by the latent heat of one pound of steam at atmospheric pressure.

Calling q the quality of the steam formed in the boiler, L the latent heat of the steam formed in the boiler, h the heat of the liqui d of the steam formed in the boiler, and t_f the temperature of the feed water, then the factor of evaporation equals

$$\frac{qL + h - (t_f - 32)}{970.4}$$

45a. Illustrative Problem.—A boiler makes 98% dry steam at 175 lb. gage pressure from feed water at 115 deg. F. What is the factor of evaporation?

$q = 0.98$; $L = 846.9$ (from Steam Table); $h = 350.4$ (from Steam Table).

$$\text{factor of evaporation} = \frac{0.98 \times 846.9 + 350.4 - (115 - 32)}{970.4} = 1.131.$$

The equivalent evaporation per hour in this boiler would be 1.13/ × weight of water actually evaporated.

46. Boiler Efficiency.- Power boilers are operated at a wide range of loads with a more or less variation in efficiency. The limit is generally the point where the gases are not carried off fast enough and the brick work of the furnace commences to give way. This may be as high as 300% of the rating, dependent on the arrangement of the combustion system.

The efficienty of any boiler is the ratio of the heat absorbed by the water and steam in the boiler per pound of dry fuel to the actual heat value of one pound of the coal. This is the combined efficiency of the boiler and furnace.

47. Shipping and Erection.—The Babcock, Hornsby, and Stirling boilers are generally shipped in sections, the parts being erected on the job by rolling the tubes and nipples into the forging and drums. The Heine type, Cahall, and return tubular boilers are generally shipped in one piece, assembled, none of the parts requiring riveting on the job. This may have an important bearing on the selection of a type where space for entrance into a building has to be provided. Straight tubes that can be easily inspected and replaced are an important feature. Evaporation tests of high efficiency are not always to be taken as conclusive as they largely depend on skill of operation. For industrial plants the boiler that can be kept clean easily will probably give the best results in the long run.

48. Fuel.—Since hard coal is used in most heating boilers, cast-iron boilers are rated and tested with hard coal as fuel, but due to the scarcity and expense of hard coal in many localities soft coal is coming more and more into use, and allowances should be made for its use.

Of late, oil and gas have been used for fuel under boilers. The use of oil or gas requires a specially designed "burner" and frequently requires a specially designed fire box if good efficiency is expected.

2240 lb. good Lehigh coal will occupy about 41 cu. ft. of space. For a ton of 2000 lb., Lump will require 28.8 cu. ft., Broken 30.3 cu. ft., Egg and stove 30.8 cu. ft., Chestnut 32.8 cu. ft., and Pea 32.8 cu. ft.

Spontaneous combustion is brought about by the slow oxidation in an air supply which is insufficient to carry away the heat formed or to support combustion. Mixed lump and fine run of mine, with a large percentage of dust, piled so as to admit to the interior a limited supply of air, make ideal conditions for spontaneous combustion. High volatile matter of itself does not increase this liability to spontaneous heating. Freshly mined coal and fresh surfaces exposed by crushing lump coal, exhibit a marked avidity for oxygen.

49. Recommendations for Storing and Piling Coal.—1. Do not pile over 12 ft. deep or so any point in the interior will be over 10 ft. from an air cooled surface.

2. Keep dust out as much as possible.

3. Pile so that lump and fine are distributed as evenly as possible, not allowing the lumps to roll down from the peak and form air passages at the bottom.

4. Rehandle and screen after two months.

5. Keep away external sources of heat, even though moderate in degree.

6. Allow six weeks seasoning after mining before storing.

7. Avoid alternate wetting and drying.

8. Avoid admission of air to the interior of the pipe through interstices around foreign objects, such as timber, brick work, or porous bottoms.

9. Do not try to ventilate the interior by pipes as more harm than good is often done.

50. Fuel Consumption.—Methods of estimating fuel consumption may be based on grate areas, square feet of radiation installed, or cubic contents of buildings. The U. S. Treasury Department estimates 5 tons per sq. ft. of grate per season of 240 days, or 1 lb. of coal per cu. ft. of building contents for the same period. District heating companies estimate 500 lb. of steam per sq. ft. of direct steam radiation per season or practically 70 lb. of coal of good quality.

50a. Combustion.—Combustion, as the term is used in steam engineering, is the rapid chemical combination of oxygen with the carbon, hydrogen, and sulphur composing the various fuels. This combination takes place at high temperatures with the evolution of light and heat. It is necessary to provide for an excess of air of from 50 to 100% when burning coal, due to the inert nitrogen, of from 18 to 24 lb. of air per pound of coal. Less air results in imperfect combustion and the formation of carbon monoxide, Co.

TABLE 32.—ALLOWABLE RATES OF COMBUSTION ON HAND-FIRED BOILERS WITH NATURAL DRAFT

Grate areas, square feet	Pounds of coal per square foot grate per hour
6 or less, small	5
6 to 10, medium	8.7
10 or larger	6.6 to 10
10 to 18	6 to 10
20 to 30	10 to 15

With stokers and forced draft, sufficient coal may be burned to operate boilers 200 to 300% of rated capacity and with a combustion rate as high as 50 lb. per sq. ft. of grate per hour.

51. Smoke.—Visible smoke is composed chiefly of small particles of carbon. The actual carbon in dense smoke amounts to about 1% of the carbon in the fuel. The accompanying loss is due more to combustible gases which may amount from 3 to 10%. High CO and smoke in the stack gases represent high losses, not so much in themselves as in the indication of unburned hydro-carbons.

Some of the causes of smoke are: (1) The furnaces and the grates are not properly designed to burn the amount of fuel fired. There is no equipment on the market that will burn equally well all coals found in the United States. (2) Draft too small. (3) Unskilled firemen. (4) Combustion space too small. (5) Wood, paper, and other refuse burned. (6) Sudden space in the load. (7) Excessive loads maintained. (8) Failure of gases and air to mix. (9) Low temperature in furnace.

If the boiler setting tight and the flue gases contain no more than 12% CO_2, there is an abundance of air. If the furnace is white hot there is sufficient temperature. If there is an abundance of air, with CO in the gases, insufficient mixture is the trouble. Too small combustion space is probably the most common of all causes of smoke. The grate must be at such a distance below the heating surface that the flame will be burned out before it reaches the heating surface.

The following measures will assist in preventing smoke:

1. The coal should be supplied in small quantities and at frequent intervals.

2. The air supply should be slightly in excess of the theoretical requirements as an auxiliary supply at the front or rear of the furnace to burn the gases.

3. The furnace temperature should be sufficiently high to ignite the gases.

4. A fire brick combustion chamber designed to cause a thorough mixing of the gases and air should be provided.

5. Steam jets usually placed above the fire door are used to assist in mixing the air and gases. The best method is to admit air through small openings around the jet which acts as an injector. If allowed to run continuously, their operation costs more than the value of the coal saved.

6. Proper firing methods.

7. By use of down draft boilers and stokers.

52. Chimneys.—Chimneys are for two purposes: (1) to carry off obnoxious gases, and (2) to produce draft and so furnish power to draw air into the furnace to properly support combustion. The first requires area of cross section and the second, height.

Each pound of coal burned yields from 13 to 30 lb. of gas, the volume of which varies with the temperature. The weight of gas to be carried off by the chimney in a given time depends on three things: (1) effective area of chimney and velocity of flow; (2) the density of the gas; and (3) the friction offered by the passage of the gases. The density decreases directly as the absolute temperature and the velocity increases with a given height in proportion to the square root of the temperature. It follows that there is a temperature at which the weight of gas is a maximum. This is about 550 deg. above the surrounding air. This quantity is only about 4% greater than at 300 deg. temperature.

The intensity of draft is independent of the area of the chimney and depends entirely on the difference in weight of the outside and inside columns of air which varies as the product of the height into the difference in temperature.

To find the maximum draft with 550 deg. difference between the outside and inside temperature, multiply the height in feet above the grate by 0.007 and the product will be the draft in inches of water.

53. Chimneys for Power Plants.—The effective area of a chimney is different from the actual area due to friction of the walls. For preliminary work, Table 33 may be used for approximation. This table is based on the use of 5 lb. coal per horsepower per hour.

TABLE 33.—APPROXIMATE HORSEPOWER FOR DIFFERENT HEIGHTS AND AREAS BURNING 5 LB. COAL PER HORSEPOWER PER HOUR

Diameter (inches)	Height of chimneys and commercial horsepower											Side of square (inches)	Effective area (sq. ft.)	Actual area (sq. ft.)
	50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.			
18	23	25	27	..	..	...	...	...	...	...	...	16	0.97	1.77
21	35	38	41	..	..	...	...	...	...	...	...	19	1.47	2.41
24	40	54	58	62	..	...	...	...	...	...	...	22	2.08	3.14
27	65	72	78	83	..	...	...	....	...	...	...	24	2.78	3.98
30	84	92	100	107	113	...	...	...	...	...	...	27	3.58	4.91
33	..	115	125	133	141	...	...	...	...	...	...	30	4.48	5.94
36	..	141	152	163	173	182	...	...	...	...	...	32	5.47	7.07
39	..	...	183	196	208	219	...	...	...	...	...	35	6.57	8.30
42	..	...	216	231	245	258	271	...	...	...	...	38	7.76	9.62
48	..	...	...	311	330	348	365	389	..	...	...	43	10.44	12.57
54	..	...	...	363	427	449	472	503	551	...	..	48	13.51	15.90
60	..	...	...	505	536	565	593	632	692	748	...	54	16.98	19.64
66	..	...	...	...	658	694	728	776	849	918	981	59	20.83	23.76
72	..	...	..	...	792	835	876	934	1023	1105	1181	64	25.08	28.27
78	..	...	...	...	...	995	1038	1107	1212	1310	1400	70	29.73	33.18
84	..	...	...	...	...	1163	1214	1294	1418	1531	1637	75	34.76	38.48
90	..	....	...	...	...	1344	1415	1496	1639	1770	1893	80	40.19	44.18
96	..	...	...	...	...	1537	1616	1720	1876	2027	2167	86	46.01	50.27
102	..	...	...	...	...	....	....	1946	2133	2303	2462	90	52.23	56.75
108	..	...	...	...	...	....	....	2192	2402	2594	2773	96	58.83	63.62
114	..	...	...	...	...	....	....	2459	2687	2903	3003	101	65.83	70.88
120	..	...	...	...	...	....	....	....	2990	3230	3452	106	73.22	78.54
126	..	...	...	...	...	....	....	....	3308	3573	3820	112	81.00	86.59
132	..	...	...	...	...	...	....	....	3642	3935	4205	117	89.19	95.03
138	..	...	...	...	...	....	....	....	3991	4311	4608	122	97.75	103.86
144	..	...	...	...	...	....	....	....	4357	4707	5031	127	106.72	113.10

The following discussion and methods were published in the *Heating and Ventilating Magazine*, March and April, 1917.

The most common error made in regard to chimneys is that of not distinguishing between the size (which governs the volume of smoke they can handle) and the height (which determines the intensity of the draft). A chimney may be *high* enough yet with an *area* too small to do the work required. On the other hand, it may be *large* enough but *too low to* produce a *draft* of the strength required to pull the air through the fire and up the chimney at a sufficiently rapid rate. Either fault, or a combination of both, will result in unsatisfactory service and will require remedying.

Chimneys have to overcome their own losses consisting of the friction of the gases rubbing against the sides in their upward passage. For this reason, a circular shaped flue is most desirable; the next, square; and after that oblong with the long side not more than double the length of the short side.

The most efficient chimney, as far as draft is concerned, is one built perfectly straight from the bottom up, round (or nearly round) in the shape of the interior flue, and lined with tile, or with the interior surface made as smooth as possible by other means. There is no advantage in tapering the inside of a chimney to a smaller size toward the top for it only retards the flow of the gases.

Steel is most efficient but unless well painted is apt to deteriorate from corrosion after a very few years, especially on heating plants when inoperative in summer. Radial brick chimneys are becoming quite common. Reinforced concrete is also used.

A square chimney can hardly be figured as having its full area effective, a deduction of 10 to 15% being necessary on account of the spiral movement of the gases leaving the corners dead and inactive. With an oblong shape the effect is more pronounced, a deduction of 25% being none too much. The use of tile flues will not only aid this slightly owing to their rounded corners, but will also safeguard much of the fire risk due to mortar falling out between the bricks as time passes, and leaving openings through which a spark might pass. As the tile serves to retain the gases and smoke, it also prevents leakage which can spoil a chimney action at any time no matter how perfectly the flue may otherwise be built.

TABLE 34.—DRAFT LOSS IN FIRE

(In. of water)

Fuel	Pounds of coal per square foot per hour burned on grates								
	5	10	15	20	25	30	35	40	45
Anthracite,									
No. 3 buck	0.15	0.40	0.75	1.24					
No. 1 buck	0.10	0.24	0.44	0.68	1.00				
Pea	0.06	0.16	0.30	0.45	0.65	0.90	1.20		
Bituminous,									
Semi bituminous	0.05	0.10	0.18	0.26	0.35	0.45	0.58	0.70	0.78
Penn. Ala. Ill. & Ind	0.04	0.09	0.15	0.22	0.28	0.38	0.45	0.55	0.60
Slack	0.04	0.07	0.10	0.15	0.20	0.27	0.34	0.40	0.50
Run of mine	0.04	0.05	0.08	0.10	0.14	0.16	0.20	0.25	0.32
On chain grate	0.05	0.12	0.15	0.23	0.31	0.44	0.57	0.75	0.94

For ordinary installations the burning of 5 lb. of coal per horsepower is usually assumed. The maximum number of pounds of coal which a boiler must consume divided by the grate area in square feet will give the number of pounds of coal burned per square foot of grate

The draft losses in boilers run about as follows:

Type of boiler	Per cent. of nominal rating developed		
	100	150	200
	Loss in inches of water		
Water tube	0.25	0.40	0.70
H. R. T	0.20	0.30	0.45
Vertical	0.10	0.15	0.20

As heating boilers are seldom run at any overload, 0.25 or 0.30 may be taken as covering the draft loss in any such boiler.

Economizers add 0.30 i . to the draft loss.

Draft losses for bends : id smoke breeching are:

Steel flues per 100 ft. r , 0.10 in.; for each 90 deg. bend, 0.05 in.

Concrete per 100 ft. ru. , 0.20 in.; for each 90 deg. bend, 0.10 in.

***Note.*—Include every b nd from the boiler uptake to the stack, counting the turn upward in the stack as one bend.**

54 Operation of Determining Size of Chimneys for Power.—1. Determine the maximum number of pounds of fuel to be burned and pounds of gas required per second from the following table which is based on 18 lb. of gas per hr. per pound of coal.

REQUIRED POUNDS OF COAL AND AIR FOR HORSEPOWERS AT VARIOUS EFFICIENCIES
(Pounds of coal per boiler horsepower developed)

Total pounds of coal	4	4½	5	5½	6	6½	7	Pounds of gas per second
	Horsepower developed							
1,000	250	222	200	182	167	154	143	5.0
1,500	375	333	300	273	250	231	214	7.5
2,000	500	444	400	363	333	308	286	10.0
2,500	625	555	500	455	416	385	357	12.5
3,000	750	667	600	545	500	461	429	15.0
4,000	1,000	889	800	727	667	615	571	20.0
5,000	1,250	1,111	1,000	909	833	769	714	25.0
7,500	1,875	1,667	1,500	1,364	1,250	1,154	1,071	38.0
10,000	2,500	2,222	2,000	1,818	1,667	1,538	1,429	50.0

2. Increase the volume due to the altitude of the plant by the percentage in the accompanying table corresponding to that altitude.

Air at higher elevation than sea level expands and requires a chimney of larger area to handle the same number of pounds at the same velocity and friction loss. The table below gives the percentage of increase for various heights up to 10,000 ft. above sea level.

FACTORS OF AIR AT VARIOUS ELEVATIONS

Elevations above sea level (feet)	Air pressure (lb. per sq. in.)	Cubic feet per pound	Increase in volume (per cent.)
	14.7	13.33	0.000
1,000	14.2	13.80	0.034
2,000	13.7	14.31	0.073
3,000	13.2	14.84	0.113
4,000	12.7	15.43	0.158
5,000	12.2	16.07	0.203
6,000	11.7	16.75	0.257
8,000	10.7	18.31	0.373
10,000	9.7	20.20	0.514

3. From Art 53 determine the friction of fuel bed, breeching, and all other resistances in inches of water and add 0.2 in. for chimney loss and 0.1 in. for safety. This will be the required theoretical draft in inches of water.

4. From Diagram 10 determine the proper height of chimney to produce the necessary draft to overcome the summation of resistances using the line of proper elevation.

5. We have the height and pounds of gas, and we can read the size of chimney direct from Diagram 11, steel stacks, or Diagram 12, for brick or brick lined stacks. Modify the height found by 0.2 in. per 100 ft. or 0.3 in. per 150 ft. for stack losses.

6. Check all results so that the factors are correct and the draft sufficient to overcome all losses.

55. Residence Chimneys.—Chimneys for residences should be of ample size, never under 40 ft. high nor less than 10 × 10 in. They should be lined with tile for the best results. Where

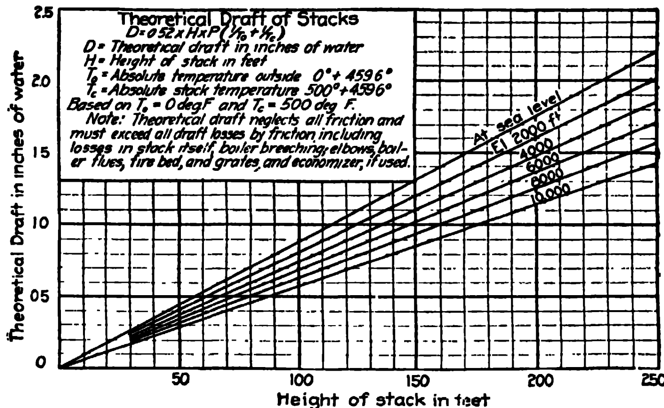


DIAGRAM 10.

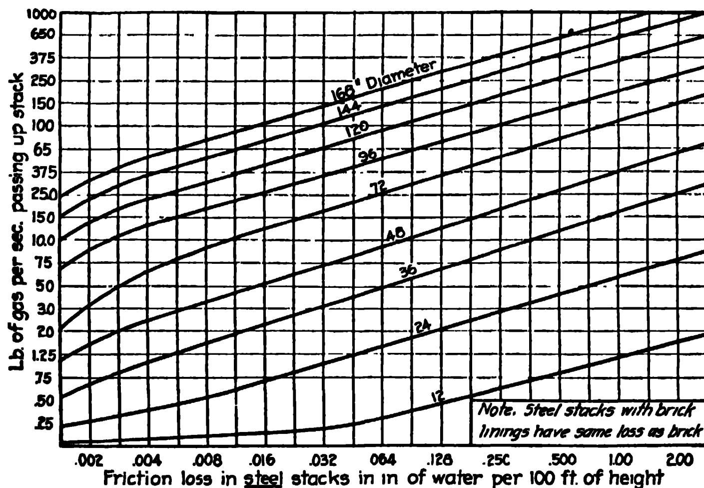


DIAGRAM 11.

the chimney is too small or has many bends, adding radiation or boiler capacity will be of little avail. Where it is impossible to obtain the height, a boiler should be provided having only direct heating surface and a minimum of flue travel. In case the chimney is efficient, the boiler can be forced and pressure or temperature raised and the system made to work. The chimney is absolutely vital and should be given first consideration.

When square or rectangular chimneys are designed for fireplaces which burn wood or bituminous coal, they are usually made with an area of 10 to 12% of the fireplace opening, while with round flues the area may be reduced to 8%. For anthracite coal the rectangular or

square flue may be reduced to 8% and the round flue to 6%. Ordinary stoves are readily served with an 8 × 8-in. flue, provided no other connections are made to the stack.

All chimney walls should be 8 in. thick to avoid danger of fire from sparks working through the joints. The building laws in some cities demand not only 8-in. walls but tile linings as well.

The height of residence chimneys is the most important element in the house heating problem and more failures are due to chimney faults than to any other cause, inasmuch as a high flue is difficult to obtain due to the low heights of buildings.

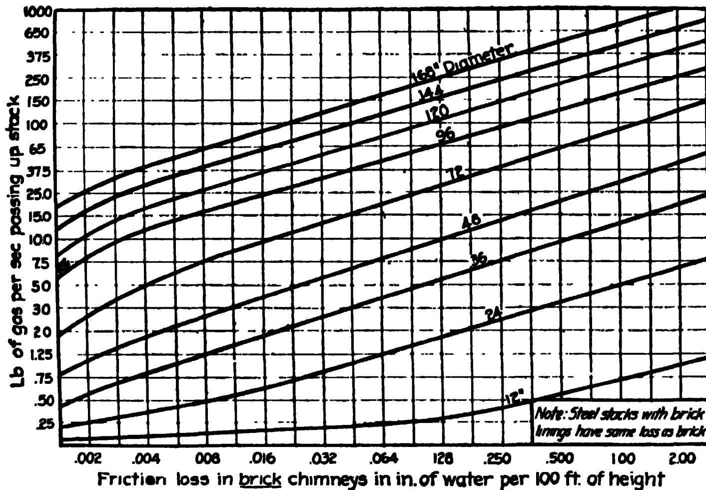


DIAGRAM 12.

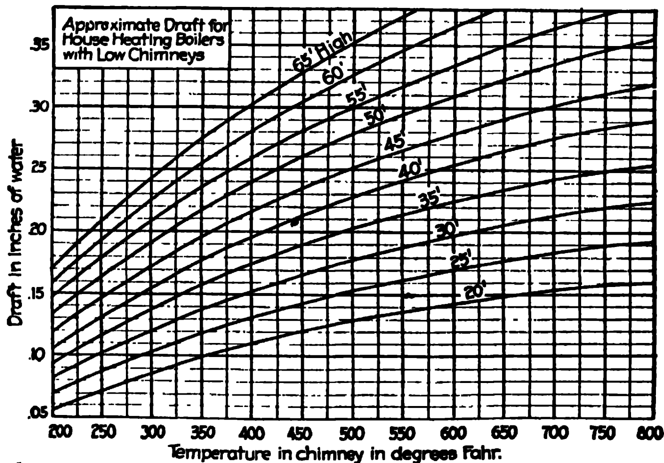


DIAGRAM 13.

Diagram 13 gives the available net draft less friction, for different heights and flue temperatures. Table 35 gives the capacity in pounds of coal per hour, square feet of standard radiation, and horsepower of work for different sizes of commercial flue tile when used as chimney linings. If the flue temperature and height is known and the draft pressure determined in inches of water, all that remains is to select a type of boiler that will furnish the required capacity with

that available draft rather than from the catalogue ratings. The boiler manufacturer will have to be consulted in cases where this determination is desirable. The table is made out for a flue temperature of 400 deg. and 10% capacity must be deducted for 300-deg. flue temperature. In larger plants, the buildings are higher and the chimney height as a rule solves itself and all that is necessary is to determine the proper cross section.

The following formula was deducted by the American Radiator Company in the *Ideal Heating Journal*, July, 1914, and is supposed to be the latest data for house heating chimneys by the very ablest engineers.

TABLE 35.—CAPACITY OF COMMERCIAL TILE WHEN USED AS CHIMNEY LININGS (Temp. of gas 400 deg.) 25 cu. ft. gas per lb. of fuel

(See chart for pressure in inches of water)

	1	2	3	4	5	6	7	8
Commercial size of tile (inches)	Thickness (inches)	Perimeter (inches)	Area (sq. in.)	$\sqrt{0.1\ (\text{area})^3}$	$\left(\frac{\text{Perimeter in inches}}{\times\ 3.73}\right)^{\frac{1}{2}}$	Pounds coal per hour $\left(\frac{\text{col. 4}}{\text{col. 5}}\right)$	Horsepower 34½ lb. steam, 5 lb. coal	Square feet standard direct radiation 0.25 lb. per sq. ft. col. 7 × 138
Outside measurement								
8½ × 8½	¾	24.0	36.0	68.0	9.46	7.2	1.44	198.7
8½ × 13	¾	35.0	71.0	189.0	11.4	16.6	3.32	458.2
8½ × 18	¾	45.0	104 0	335.0	13 0	25.8	5.16	712.2
13 × 13	1	48.0	144 0	546.0	13.4	48 2	9 64	1330.0
13 × 18	1	54 0	176.0	738.0	14.2	52 0	10 4	1,435.2
18 × 18	1	64.0	256.0	1,295.0	15.45	83.8	16.76	2,313.0
Inside diameter (round)								
8	¾	25.13	50.3	113.0	9.64	11.7	2.34	323.0
9	13/16	28.27	63.6	160.5	10.25	15.7	3.14	433.3
10	⅞	31.44	78.54	220.0	10.77	20.4	4.1	566.0
12	1	37.7	113.1	380.0	11.85	32.07	6.41	885.0
15	1⅛	47.12	176.7	744.0	13.25	56.2	11.24	1,551.0
18	1¼	56.55	254 5	1,281.0	14.52	88.4	17.7	2,443.0
20	1⅜	62 83	314.16	1,758.0	15.29	115.0	23.0	3,174.0
22	1⅝	69.12	380 0	2,342 0	16 05	146.0	29.2	4,030.0
24	1⅝	75.4	452 4	3,030.0	16.76	181.0	36.2	4,996.0
27	2	84 8	572 6	4,340.0	17.77	241.0	48.8	6,734.0
30	2⅛	91.25	706 8	5,940 0	18.44	322.1	64.4	8,888.0
33	2¼	103.7	855.3	7,906.0	19.66	402.0	80.4	11,095.0
36	2½	113.1	1017.9	10,270.0	20.53	500.0	100.0	13,800.0

Reduce capacity 10% for 300 deg. stack temperature.
Draft in inches of water per 100-ft. height, 300-deg. stack temperature, 0.435 in.
Draft in inches of water per 100-ft. height, 400-deg. stack temperature, 0.550 in.

H = height of chimney.
d_a = draft pressure in inches of water to overcome resistance of flue, furnace, stack and produce velocity.
P = perimeter of flue.
a = area of flue in square inches.
C = coal per hour.

For 400-deg. stack temperature.

$$H = \frac{164 d_a}{1 - \frac{3.73 P C^2}{a_a^2}} \tag{1}$$

For 300-deg. temperature

$$H = \frac{206d_a}{1 - \frac{4.14PC^2}{a^4}} \qquad (2)$$

If 10% is allowed for stack friction, for 400-deg. temperature the last term of the denominator will equal 0.1, and solving for C we have

$$C = \sqrt{\frac{a^3}{37.3P}} \qquad (3)$$

For 300-deg. temperature

$$C = \sqrt{\frac{a^3}{41.4P}} \qquad (4)$$

Knowing the draft in inches of water, the height of stack will be, with 10% for friction

$H = 182.2d_a$ for 400-deg. temperature.
$H = 230d_a$ for 300-deg. temperature.
$d_a = 0.00435H$ for 300-deg. temperature.
$d_a = 0.0055H$ for 400-deg. temperature.

Most manufacturers give the size and height of chimney necessary for each boiler. Down draft boilers and some sectional boilers require a more intense draft than others, especially the round boilers.

55a. Recommended Height and Size of Chimney.—The ordinary residence usually employs a chimney between 25 and 60 ft. high, the area being proportional to the size of the house. It is possible to burn No. 1 buckwheat coal with a chimney 55 ft. high if the fire bed is not made too thick. Down draft boilers should have chimneys at least 60 ft. high to operate successfully.

Having a chimney built upon desirable lines as far as draft is concerned, it may, of course, still be too small, and in this connection it might be said that no flue should be made less than 10-in. diameter or 10 × 10 in. square. Table 36 is by Prof. Carpenter, giving data on heights and areas of house heating chimneys with the approximate cubic contents heated, for preliminary work or estimates.

Table 36.—Prof. Carpenter's Standard Table of Chimney Dimensions

Approximate cubic contents of building (gross)	Standard square feet of radiation	Height of chimney flue (feet) Diameter of chimney flue (inches)				
		30 ft.	40 ft.	50 ft.	60 ft.	80 ft.
12,500	250	7.0	6.7	6.4	6.2	6.0
20,000	500	9.2	8.8	8.2	8.0	6.6
45,000	750	10.8	10.2	9.6	9.3	8.8
60,000	1,000	12.0	11.4	10.8	10.5	10.0
90,000	1,500	14.4	13.4	12.8	12.4	11.5
140,000	2,000	16.3	15.2	14.5	14.0	13.2
240,000	3,000	18.5	18.2	17.2	16.6	15.8
320,000	4,000	22.2	20.8	19.6	19.0	17.8
400,000	5,000	24.6	23.0	21.6	21.0	19.4
480,000	6,000	26.8	25.0	23.4	22.8	21.0
560,000	7,000	28.8	27.0	25.5	24.4	23.0
640,000	8,000	30.6	28.6	26.8	26.0	24.2
810,000	9,000	32.4	30.4	28.4	27.4	25.6
900,000	10,000	34.0	32.0	30.0	28.6	27.0

The chimney top should run above the highest part of the roof and should not be less than 40 ft. above the boiler in height or less than 10 × 10-in. on the outside. It should be so located with reference to any higher buildings nearby that wind currents will not form eddies and force the air downward in the flue. A shifting cowl, which will always turn the outlet away from the adverse currents, will promote better draft.

The flue should run as nearly straight as possible from the base to the top outlet. The outlet must not be capped so that its area is less than the area of the flue. The flue should have no other openings into it except the boiler smoke pipe. Sharp bends and offsets in the flue will often reduce the area and choke the draft. The flue must be free of any feature which prevents full areas for the passage of smoke. It should be lined with tile and the joints well cemented or all space between the tile and brick work filled in tightly. There must be no open crevices into the flue where the sections meet, otherwise the draft will be checked. If the flue is made of brick, the chimney should have outside walls at least 8 in. thick to insure safety. The inside joints should be well struck; each course should be well bedded and free from surplus mortar at the joints. However, all such chimneys should be tile lined rather than to take chances on the operating results of the whole heating system.

If there is a soot pocket in the chimney below the smoke pipe opening, the clean out door of same should always be tightly closed. If this chimney flue has other openings into it—from fireplaces or other connections—these openings will check the draft and prevent best heating results from the boiler and should be eliminated.

The smoke pipe should not extend into the flue beyond the inside surface; otherwise, the end of the pipe cuts down the area of the flue. The joints, where the smoke pipe fits the smoke hood of the boiler, should be made tight with putty or asbestos cement, and asbestos cement should be used to seal the joint between smoke pipe and chimney opening. For the best results, place the chimney within the building where it is warm rather than outside where it is cold.

56. Induced and Forced Draft.—In nearly all power plants, stokers have taken the place of hand firing where there are more than 300 to 500 hp. and in some cases smaller plants are so equipped. Induced draft and forced draft are both used as a rule. The former is supplied by the chimney and the latter by blowers. The chimney is then only required to supply power to remove the gases after combustion.

In a well designed plant these two methods of producing draft are arranged so as to maintain a certain constant balance sufficient to supply the fuel bed with just the correct amount of air. The fan supplies the air with proper variation in pressure and volume by means of speed regulators. In large plants of this character, the kind of fuel and variation in load enter into the problem. Special experience is necessary in designing such systems, and stoker and fan manufacturers are always ready to assist with expert advice. The pressures and volume of air are calculated the same as for chimneys, only the power is applied in such manner that the circulation is independent at all times of the temperature.

57. Economizers.—Economizers consist of a series of vertical cast-iron tubes placed in the flue between the boiler and chimney through which the feed water passes and absorbs the heat of the flue gases above the actual temperature requirements for draft of say 350 to 400 deg. F. The tubes are provided with mechanical scrapers to keep them from being fouled with soot. Economizers require by-passes for both the gases and feed water. They are very heavy and cost per horsepower nearly as much as the boilers. By arranging the flow of the flue gas and water on the counter-current principle, the water can be heated to the final temperature of the gas in a properly designed system.

Where very high steam pressures have been carried, cast-iron tubes have been known to fail. Improvements in combustion apparatus, however, have considerably reduced the available waste in heat. There is undoubtedly about 10% saving in the use of this apparatus, as the feed water can be heated to over 300 deg. F. with waste products. Economizers also take care of the unavoidable waste in flue temperature where great overloads are carried. By placing the feed water pump between the economizer and boiler, the excessive boiler pressure on the economizer is avoided and all danger is obviated.

Economizers are used in connection with hot water forced circulation heating systems in conserving the waste heat of chimney gases, brass furnaces, etc. There is no increase in economy over heating the feed water as it is merely diverting this source of heat from one purpose to another. They cannot as a rule be installed as a portion of the heating equipment solely and show a commercial saving on the investment due to the comparatively short duration of the heating season.

58. Mechanical Stokers.—It is acknowledged, except in the case of the smallest units under 300 hp., that for all plants, mechanical stokers and coal and ash handling machinery are absolutely necessary to reduce labor costs, eliminate smoke, and burn the fuel at rates covering a wide range of loads as well as to conserve equipment and reduce fuel charges.

For the selection of a stoker, the fuels should be classified as follows: (1) Coking and non-coking coals, (2) clinkering and non-clinkering coals, and (3) high and low ash coals.

A stoker should embody the following functions:

1. Feed the fuel at the proper rate.
2. Burn the fuel economically by employing the exact requirement of air.
3. Automatically discharge all the refuse and ash without waste in unburned fuel.
4. Automatically keep the air spaces and passages free without any by-passing of air.
5. It should not require the frequent disturbance of the fuel bed with the furnace open for the spreading of fuel to prevent air holes and removal of clinkers.

It is therefore natural that under the wide requirements of load and service with the variation in grade and type of fuel furnished, that all the conditions of service will not be fulfilled at all times with any one type of stoker; at best, all that can be done is to make a selection that will fulfill the major portion of the requirements.

Stokers may be divided into three types with slightly different arrangement for forced or natural draft: (1) chain grate, (2) over feed, and (3) under feed. Omitting the elements of first cost, relative workmanship and materials entering construction, the following are a few of the considerations that may be of assistance in the selection of type of stoker for any particular service.

For eastern coals with low ash and slight tendency to clinker, most stokers will give good results with proper handling provided too heavy overloads are not attempted. These are coals of the coking and caking class requiring agitation of the fuel bed at least in the early stages of combustion. For this reason, movable grate bars must be used which, at times, give trouble from warping or burning when pushed into the fuel bed, especially when there is sulphur present in the fuel. The over feed with inclined grate is apt to let the fuel through the grate before complete combustion takes place when forced too hard. There is also a tendency to form clinker making it necessary to provide clinker crushers.

For anthracite, coke braise, and western coals with high ash, the chain grate is apt to be more successful as it automatically dumps all ash and a fresh clean grate surface is presented as the grate revolves. The grate area for all chain grates is large and they function particularly well with natural or induced draft. The size and length of the combustion arch when used with the chain grate is an important factor in determining the amount of fuel that can be burned or the rate.

Stokers of the overfeed and chain grate type require a combustion arch which, in itself, is no particular disadvantage outside of initial expense and maintenance costs, as it is a very effective aid to the combustion of soft coal for any type of furnace.

The under feed stokers occupy relatively small space and require forced draft. The combustion arch, however, is unnecessary. They give excellent results with coking and caking coals as the green fuel is forced up through the fuel bed, breaking up the coke masses with unlimited air supply both as to volume and pressure. This arrangement enables heavy overloads to be carried with excellent results as far as combustion is concerned. With high ash coals and heavy overloads the very high resulting furnace temperatures cause the ash to fuse forming clinker. This tendency varies with the rate of combustion and percentage of ash in the fuel.

There seems to be a tendency to make the overload capacity or range the most important requirements for stoker equipment. This may be all right from a combustion standpoint of efficiency, but most stoker troubles seem to originate from this cause. From a common sense standpoint, any program that provides for continuously excessive overloads is bad practice, especially in view of the class of labor which the ordinary manufacturer deems capable of handling his fuel, the cost of which may amount to from $75,000 to $200,000.

It makes little difference what stoker is used as the furnace temperatures made necessary by these overloads are certain to break down the brick work and put the boiler unit out of com-

mission for two or three weeks at more frequent intervals than if a more conservative operating load were maintained. During a few weeks in December public service plants are subject to extreme loads for a few hours a day. These are entirely out of their control and the service has to be maintained. This feature is exceedingly important due to the necessary increase in the amount of equipment on which fixed annual charges have to be maintained.

For industrial plants with the load more regular and entirely under control of the management, it would seem better practice to operate nearer the normal boiler rating with better evaporation, less repairs, and sufficient equipment, and such overloads as to reduce to a minimum the stand-by losses due to shifting boilers during the daily run. These stand-by losses may be reduced likewise by employing larger boiler units with fewer fires wherein a smaller percentage of overload would give a wider range in capacity.

With a rating of 10 sq. ft. of boiler heating surface, a 100% overload would mean a reduction of 50% in heating surface or 5 sq. ft. per hp. which must of necessity reduce the evaporation, increase the flue temperature, and reduce the life of the furnace and settings.

With a 25 to 50% overload and 8 to 6 sq. ft. per hp., the problem would be within range of nearly all types of stokers and advantage could be taken of some excellent features in types that might not be as adaptable if the overload feature were the paramount requirement. Certainly, the question of maintenance is independent of the type of stoker where the equipment is operated hard enough to produce destructive furnace and flue temperatures.

It is not advisable to provide equipment for the absorption of more heat than can be produced by the combustion system, and the boiler surface should be proportioned for the available chimney power rather than the work to be performed; or stated otherwise, see that the combustion system is ample in capacity before considering the boiler. This applies to all heating and power boilers although the latter are not so often handicapped with low draft pressure as they are frequently overloaded.

In the design of any power plant, high economy may be obtained by operating an excess of boiler heating surface but when the expense of maintaining this extra equipment is balanced against the actual increase in fuel economy, it will be found that over 10 sq. ft. of heating surface per boiler horsepower does not pay in over all economy. There is such a thing as operating too much boiler power on a given load.

Allowance should be made in all power plant installations for sufficient reserve boiler power in order that boilers may be cleaned at regular intervals during work periods.

POWER

59. Prime Movers.—There are two main types of prime movers for power generation: (1) reciprocating and (2) rotary engines, of which latter class the turbine will be the only one considered.

Reciprocating engines as the name implies, involves a piston moving back and forth to impart rotary motion to a shaft. This requires provision of some method of stopping or cushioning the moving parts as they change direction to overcome their inertia. This is accomplished by imprisoning some of the fluid before the end of the stroke by initially closing the exhaust valve, and is known as the compression. Reciprocating engines may be single or multicylinder, double or single acting, operated by a direct explosion of gas in the cylinder or by the expansion of a change of gas or steam at high pressure.

60. Gas Engines.—Single acting cylinders take an impulse on only one side of the piston while those double acting take an impulse on both sides. Gas engines are generally known as internal combustion engines. They are built multicylinder and single acting but the larger types are double acting, with one, two, or more cylinders.

The action of an internal combustion engine is as follows: The charge is drawn in compressed, and fired by an electric spark producing the motor impulse and the products are next expelled, so there is an impulse only once in two revolutions for each end of the cylinder. For this reason, high speeds, very heavy fly wheels, and multicylinders are provided in order to store sufficient energy to provide for the infrequency of the impulse and enhance smooth running.

They are difficult to regulate to the constant speed required for electric power generation, especially in the larger types with low speeds. The cylinders have to be water jacketed with a circulating system and in the larger sizes the pistons and piston rods have to be cooled. Their cost is very great although their fuel economy is unquestioned as compared with the steam engine, being about ⅓ of a pound of coal per horsepower or about 4000 B.t.u. They may be operated with natural, blast furnace, or producer gas, a heavy fuel oil, the engine using the latter being known as the Diesel motor. This engine depends on the high temperature of compression for ignition and explosion of the fuel charge.

The erratic performances of gas engines have been due largely to variations in the composition of the fuel gas and its resulting air requirements. Back fires are frequent, due to a charge exploding in the exhaust after leaving the engine, and sometimes difficulties are experienced with the noise of the exhaust. If there are no sulphurous or injurious products in the exhaust gas, a small water jet close to the engine will remedy the trouble. If sulphur or other impurities are present, the pipe eats out very rapidly, but these jets can then be replaced by a heater with cooling surface as close to the point of emission of the gases from the engine as practicable.

61. Steam Engines.—Steam engines are almost entirely of double acting type. Where two cylinders are used, one exhausting into the other, they are known as compound; where three are used, one exhausting to the other, they are known as triple expansion engines. The latter, at present, are confined almost entirely to marine practice. Where two cylinders are on the same piston rod, one behind the other, they are tandem compound and when connected to the shaft, either side of flywheel, they are cross compound.

Engines are also classed as to rotative speed, as high, medium, and low, although by varying the stroke they may at the same time have the same piston speed. The steam engine acts on a pressure volume basis with the work divided as nearly as possible between the cylinders when in multiple. For economy, the cylinders should have a certain volumetric relation to the changes in volume of the steam between the final and initial pressure.

When the final terminal pressure is reduced below atmosphere by condensing the steam, a further classification is made as condensing and non-condensing engines. The steam enters the cylinder at an initial pressure up to the point of cut off—generally ¼ to ½ the stroke—and is expanded producing a mean average pressure on the piston areas. The number of times this initial volume of steam is expanded before leaving the engine is termed the number of expansions. It is the reciprocal of the cut off divided by the ratio of the cylinder areas. With ¼ cut off and a ratio of cylinders 3 to 1, the ratio of the expansion would be 1:12 and the number of expansions 12 for that particular engine. The fixed quantities with any engine are the ratio of cylinders and speed. The only variable is the point of cut off, which is limited for economy to ¼ to ½ the stroke.

There is often confusion in steam rates of reciprocating engines and turbines, as the former are rated in pounds of steam per indicated horsepower, and the latter in brake horsepower, because their design prevents the use of an indicator. In the case of direct current, turbines are rated in pounds of steam per kilowatt-hour delivered at the switchboard. In the case of alternating current they are rated in kilo-volt amperes (k.v.a.), on account of a variable power factor of from 80 to 90%, depending upon the construction of the alternator and the nature of the load. The volts and amperes as read from the switchboard is termed the apparent voltage. The actual kilowatt load is the kilovolt-ampere load times the power factor.

The reciprocating engine has a nearly constant friction load of from 10 to 20% of the rated load, and it can be seen that the rate at one-half load will be much higher than at full load.

The indicated horsepower therefore includes all power due to losses in generator, friction load of the engine and generator, and when divided into the total steam used, would give a lower apparent rate than the turbine when the total steam is divided by the net available load at the switchboard.

Automatic high speed engines have comparatively high rotative speed with short stroke and are generally operated non-condensing. They enable a less costly generator to be used due to the high rotative speed and are very flexible in that a wide variation in the load and terminal pressure may be obtained with fair average steam rate.

There are four common types of engine valves: (1) the balanced piston valve, (2) the unbalanced D-slide valve and gridiron valve, (3) the Corliss type valve, and (4) the poppet valve. Each type is actuated by an eccentric and a governor from the main flywheel shaft in such a manner that it admits and releases alternately the proper amount of steam to and from the cylinder to take care of the load on the engine.

The piston valve slides back and forth in a cylinder parallel to its axis and alternately opens and closes the inlet and exhaust ports of the main cylinder. It is called a balanced valve for the pressure is equalized on both ends, thus reducing the friction. It is difficult to keep this type tight. A modification of this type is the riding cut-off of the Buckeye engine that has one sleeve working inside the other, one attached to a rod actuated by the governor for cut-off and the other, the main valve, attached to the shaft eccentric and having a fixed travel.

The D-slide valve is an arched plate sliding over a series of steam and exhaust ports known as the gridiron. This valve is not adjustable for wear and is difficult to keep steamtight. It is an unbalanced valve—that is, the pressure is much greater on one side than on the other—which causes much attendant friction in sliding over its seat or grid. A modification of this valve is provided with a pressure plate with adjustable volts to take up wear and release the valve proper of the pressure, thus enabling it to be kept steamtight.

The Corliss valve gear consists of an eccentric which actuates a wrist plate, which in turn actuates two steam valves and two exhaust valves. Dash pots quickly close the steam valves at the proper time when the governor releases them from the wrist plate connection. The valves themselves are small rotating cylinders. They rotate back and forth through an angle of about 130 deg. Since they have a small area exposed to the live steam pressure, they are subject to much less friction than the D-slide valve, they operate more easily, and are less liable to wear, and more easily kept tight.

The poppet valve, instead of rotating or sliding as in the three former cases, rises and lowers on a seat. It is circular in form and has a beveled edge to fit its seat. There are four of these valves for each cylinder as in the case of the Corliss type, two steam valves and two exhaust valves. The length of time that the steam valves are open is governed by the load on the engine by means of a fly-ball governor geared to the main shaft. Poppet valves are well adapted to the use of superheated steam on account of its tendency to cut furrows in the metal under sliding valves.

In all single valve engines, it requires care in setting the valve as all functions of opening for the admission and closing the exhaust for compression have to be accomplished with a single movement. There are a number of medium speed engines having short stroke and fairly high speeds with Corliss valve gear for variable load conditions and terminal pressure. In many cases, they are compounded and operated condensing. They are known as four valve engines and combine the principles of the Corliss valve with comparative high rotative speed.

Nearly all reciprocating engines are counter-flow, that is, the steam flows in and out at the same end causing cylinder condensation due to the varying temperatures of the expanding steam in contact with the cylinder walls. The Unaflow engine which exhausts at the center of the cylinder, takes its name from the fact that the steam flows in one direction. They claim a perfectly tight valve is the reason for their economy. These engines are adpted to superheated steam by using a long stroke and small diameter and operating non-condensing. By so doing great economy may be obtained. There will naturally be small economy of condensing with one cylinder when the equipment cost is considered.

61a. Compounding.—Where very high pressures and steam temperatures are available, it pays to compound the engine on account of cylinder condensation. Compounding does increase the bulk of the engine but it does not increase its rated load. Where small units are necessary and non-condensing conditions are maintained, a lower steam pressure and higher speed will give the best overall results, especially if there is a vacuum heating system in which to use the available exhaust. Also the fluctuations of the heating and power are not so serious on a small installation.

Where engines are over 500 hp. they should be compounded, using high steam pressures and operating condensing. A large engine is seriously reduced in economy by operating it non-

condensing when designed for condensing conditions. Better overall economy due to low installation cost is obtained by condensing, using high pressure live steam for heating, due to the reduction of the engine economy, and the lack of heat balance between the heating and power with a constant steam power rate. This is amply proven by cotton mill practice in New England where the main engines are operated under high vacuum, and high pressure steam is used for heating.

Table 37 is interesting as showing the reason why high vacuums (above 26 in.) do not produce an overall economy as great in proportion to the cost with reciprocating engines. They work on a difference in pressure for an interchange in heat since the cylinder areas and piston speed are fixed. Column 1 gives the absolute pressures, Column 5 gives the total heat. It shows that in Column 9 a constantly decreasing rate in pounds pressure per B.t.u. which is 3.3 for atmosphere, 2.375 for 25 in. of vacuum, and 1.8 for 28 in. of vacuum. These physical characteristics are borne out in practice.

It is impossible to obtain in a reciprocating engine the highest economy and flexibility of load. There is a point at which any engine will do better, depending on the elements of design already discussed. Therefore, in selecting a type of engine, its design should be modified so as to be most economical under the conditions of major operation, and at the same time furnish the full required power load under all conditions of operating pressures.

Table 37.—Relation of Volumes and Pressures of Steam as Affecting the Economy of Turbines and Engines

Absolute pressure (lb.)	Gage pressure (lb.)	Temperature of steam (deg. F.)	Difference in initial and final pressure (lb.)	Total B.t.u. per lb.	Difference in B.t.u. per lb.	Volume per lb. cu. ft.	Difference in volume (cu. ft.) Final and initial pressure	Difference between final and initial pressure	
								Pounds pressure per B.t.u.	Cu. ft. volume per B.t.u.
(1) Steam table	(2) Steam table	(3) Steam table	(4) 165 − Col. 1	(5) Steam table	(6) 1195 − Col. 5	(7) Steam table	(8) Col. 7 − 2.754	(9) Col. 4 ÷ Col. 6	(10) Col. 8 ÷ Col. 6
165.0	150	366	0	1195	0	2.754	0		
14.7	0	212	150.3	1150	45	27.0	24.3	3.3	0.54
9.34	10″ vac	190	155.7	1142	53	41.0	38.3	2.94	0.723
4.74	20″ vac	160	160.3	1130	65	77.0	74.3	2.46	1.143
1.94	26″ vac	125	163.0	1115	80	178.0	175.3	2.375	2.23
0.95	28″ vac	100	164.0	1103	92	351.0	348.3	1.8	3.82

62. Steam Turbines.—There are three types of tubines; (1) the impulse wheel wherein the steam is first expanded through a nozzle, (2) the reaction type, and (3) the several combinations of the two.

All turbines are very uneconomical and the load capacity goes down rapidly with reduced vacuum, but the impulse wheel under the conditions of design for full vacuum will have less capacity than the reaction type for loss of vacuum. The reason for the effectiveness of high vacuum in the case of turbo-generators is shown in Table 37, Column 10. The cubic feet per B.t.u. for atmosphere is 0.54, for 10-in. vacuum 0.723, for 20-in. vacuum 1.143, for 26-in. vacuum 2.23, and for 28-in. vacuum 3.82, or 28-in. vacuum is over 1½ times as effective as 26-in. vacuum. These are not quite true ratios but are simply given so as to convey the physical reason for these conditions.

62a. Impulse Type.—If a nozzle is arranged so that the difference in area of the inlet and the outlet end corresponds to the initial and terminal volumes of the pressures, the steam will be fully expanded and the entire pressure transformed into velocity. Table 37 gives the volume at 150 lb. as 2.754 cu. ft. per lb., and at 28 in. of vacuum as 348.3 cu. ft. per

lb. so the relative areas would be $\frac{348.4}{2.754} = 127$ times. However, when steam is expanded there is no increase in velocity beyond that corresponding to about 60% of the initial pressure. This steam pressure would all be changed to velocity and if it strikes a moving vane at twice the speed of the vane, it will be operating under conditions of maximum economy. In practice these vanes and nozzles are divided in stages as there is a limit to the speed that a disk of this kind can operate without rupture. This is the principle of the impulse turbine and any change in the terminal pressures requires a change in the nozzle relation, or the economy suffers. So long as they operate under the condition for which they were designed the economy will be slightly greater than for the reaction type. The stationary blades are used simply to change the direction of flow to enter the next wheel.

62b. Reaction Type.—The reaction type is a series of stationary blades on the stator or cylinder between which the moving blades on the rotor or spindle revolve. The velocities are not so great and the action is one entirely of steam expansion and reduction of pressure in the buckets themselves there being no nozzles.

62c. Impulse Reaction Type.—This is a combination of the two types utilizing nozzles and impulse wheels in the high pressure stages and reaction blading in the low pressure or vacuum stages.

There are various other types of impulse and reaction turbines, such as low pressure and mixed pressure. These are extremely economical where exhaust steam is going to waste from any source, such as from steam hammers. The fluctuation of the available exhaust steam to make the power supply constant is supplemented by passing live steam through a reducing valve with some attendant superheat or by adding the live steam through an impulse wheel and passing the exhaust from the hammers in between the impulse wheel and the reaction blading. With 28-in. vacuum a kilowatt can be generated with about 35 to 40 lb. of exhaust at 16-lb. absolute pressure.

In bleeder turbines, the same scheme is used as extracting steam from the receiver of a reciprocating engine but in a different form. This steam can be bled at 5 lb. pressure up to about 25 % of the capacity of the machine. The economy for the power recovery is no greater than any high pressure turbine exhausting at 5 lb. back pressure, and as a rule the steam rate for this portion would be over 40 to 50 lb. per kw. The terminal pressure will always fix the steam rate of any engine within limits.

Due to the fact that economical turbines require such high speed, it would be impossible to commutate with direct current direct-connected generators. There is the alternative of sacrificing economy by a reduction of speed in direct connecting, or resorting to reduction gears. It is always a good idea to avoid gears wherever possible by using some other method. Alternators and motor generators give one solution.

63. Superheated Steam.—The use of superheated steam is more economical on any engine or turbine than saturated steam, the economy being inherent in the physical properties of the steam rather than being due to the type of engine, as a greater volume of steam at any pressure is obtained with superheat from a given weight of water making a greater pressure range for a given amount of heat. It will, however, decrease the wear on the blades which deteriorate rapidly when entrained water is in the steam. It also reduces the cylinder condensation when used in reciprocating engines, although the latter, for very high steam temperatures, require poppet valves and a different types of construction than the regular engine. These advantages are additional to those previously scheduled.

64. Comparisons of Engines and Turbines.—For first cost, condensing conditions, space occupied, simplicity and durability, the turbo-generator cannot be surpassed. For non-condensing conditions, the reciprocating engine is better, as well as for conditions for large units where low vacuum (26 in. and below) only is available. Even in the latter case, the advantages over the turbo-generator are but slight.

The most economical arrangement for power as far as operation is concerned, is the combination of the reciprocating engine for the steam between the initial pressure and atmosphere and the use of a low pressure turbine between atmosphere or 16 lb.absolute and 28 or 29 in. of

vacuum. The first cost and space of a new installation does not warrant the investment over the condensing turbine but where the engines are already installed it is an excellent method of improving the economy. A fairly large unit will furnish a kilowatt on between 35 to 40 lb. of exhaust steam after passing the reciprocating engine.

65. Condensing Water Required.—The condensing of steam to produce a vacuum and reduce the back pressure involves the absorption of the latent heat of the steam of about 1040 B.t.u. per lb. and the removal of all extrained air. The amount of water necessary to cool a pound of steam if its outboard temperature is limited to 90 deg. and its entrance temperature to 70 deg. as is possible in summer, is $\frac{1040}{20} = 52$ lb. per lb. of steam. As some of the heat has already been taken up by radiation and in the form of entrained moisture, 950 to 1000 B.t.u. per lb. can be used as the latent heat of the exhaust steam.

66. Removal of Entrained Air.--If there were no air present, the temperature of the condensate from a condenser would indicate the vacuum or absolute pressure. The amount of air present is determined by the relation of this temperature with the corresponding pressure; as the pressure is that is desired for economy, the removal of the air must be accomplished by a dry air pump. The question of air removal is not as serious in vacuums below 25 in. but becomes absolutely by imperative for vacuums from 25 to 29 in. When the air is handled by one pump and the condensate by another, the system is known as dry. When only one pump is used for both air and water, it is known as the wet system.

67. Condensers.—Condensers are classed as surface condensers and jet condensers. The former require tube heating surface with cold water pumped through the tubes, and jet condensers have a jet of water mingling with the steam. Surface condensers cost more but where water for the boilers is bad, they pay for themselves in a short time due to the re-use of the purified condensate, to say nothing of the heat contained in the returned water. In case the vacuum drops on a surface condenser it will recover, but with the jet types, if it goes anywhere near as low as 10 in., it will break and the machine will have to be shut down to reestablish the vacuum. The surface condenser will use less injection water and by increasing the surface and pumpage, much higher temperatures may be used than with the jet condenser without breaking the vacuum.

68. Auxiliaries.– Dry air pumps, circulating pumps, and similar auxiliaries are generally operated by independent steam driven units inasmuch as with high vacuums it is necessary to use some exhaust steam to raise the condensate from 120 to 210 deg. for feed purposes. This may be a source of waste if too little attention is paid to the amount of power obtained before the exhaust steam is utilized; for instance, small non-condensing turbines sometimes use more steam than that required by the main units. It is just as important to obtain a fair water rate and corresponding power recovery from this auxiliary steam as from the main units.

There are numbers of plants that would show a saving if live steam were used to heat the feed water and the auxiliary were condensed, because so little actual efficient power generation is obtained from this steam. Especially is this true if there is a waste to the atmosphere from fluctuation of the load. This can be avoided by operating part of the auxiliaries electrically.

Where there are no ponds or natural sources of water supply, a system of cooling may be installed based on an air supply or the mechanical evaporation of water. There are two methods: (1) cooling towers and (2) spray ponds.

Cooling towers are of four classes: (1) natural draft closed type, (2) forced draft, (3) natural draft open type, and (4) natural and forced draft combined. The cooling of the water in towers is accomplished by evaporation, convection, and radiation, but mainly by evaporation. It is necessary to evaporate in the tower an amount of water equivalent to the condensate but as a matter of fact, the loss and use of water from a cooling tower is less than when the engines exhaust to the atmosphere. Assuming a non-condensing engine uses 40 lb. of steam per kw.-hr. at the switchboard, all except 10% retained for heating feed water, is exhausted to the atmosphere and lost. A cooling tower and condenser would use not more than 25 lb. per kw.-hr. or save about 30%.

Where land is available, a spray pond is the least costly method of cooling injection water. The idea is to spray a film of water into the air bringing as great a surface in contact with the surrounding air as possible. Both cooling towers and spray ponds are apt to throw water in finely divided drops on surrounding property, and this fault should be cared for in selecting any system as well as its location. The Ford Motor Company uses the roof of one of its buildings as a spray pond and all of the condensing capacity for the main engine plant is handled in this manner; there is, however, considerable fine spray thrown when the wind blows heavily from certain directions, although not in any way serious.

PIPING AND FITTINGS

69. Pipe.—Standard pipe may be used for any and all purposes in heating and power work as it is tested to 500 lb. pressure and over. The relative values of steel and wrought-iron pipe are at present one of cost. Wrought-iron pipe as made by Byers Company is probably purer iron which accounts for its longer life. In steam heating systems it makes little or no difference except in the case of the return pipes which deteriorate more rapidly than in any other service. In hot water systems if the water is not changed in the system so as to admit air, either wrought iron or steel lasts indefinitely. If the water is changed and the air is allowed to enter the system dissolved in the water, there is apt to be trouble in any case. Steel pipe made by the Bessemer process is apt to have impurities. Impure places are generally the points where chemical action shows first. Water pipes for domestic service, even when galvanized, are short lived in many cases.

The secret of non-corrosion in all piping is the purity of the iron, whether steel or wrought iron. The latter, due to its process of manufacture in a puddling furnace, is apt to be purer metal but this carries no assurance of the fact. Table 38 is a complete list of standard pipe dimensions.

70. Joints and Flanges.—In all high pressure piping and in fact where large sizes are used for any purpose, bends should be used to eliminate fittings and joints. For high pressure work there are four types of joints: (1) the screwed joint, (2) the Van Stone joint, (3) the welded joint, and (4) the shrunk joint. In the last two cases the pipe is rigidly and permanently fastened to the flange by shrinking or welding. In the case of the Van Stone or Cranelap, the flanges are loose on the pipe and the laps of the pipe are clamped between them.

Flanges are made of cast iron and forged steel. In all cases the face of the joint should be machined. The Van Stone joint with a perfectly smooth finish to the laps of the pipe, makes the best joint although some prefer the other types. Flanges of all types are made standard and of extra heavy cast iron, or extra heavy steel for superheated steam.

There are various types of gaskets on the market which serve well for this service, such as corrugated copper which is all right for saturated steam. Corrugated steel should be used for superheated steam. Plain rubber or "rainbow" with screwed flanges, is best for hot water and steam heating. In some stations, ground joints are used with no gasket, the faces of the joint being ground off until they fit perfectly. Some years ago one face was actually ground against another. Using rough surfaces, several kinds of material in the gaskets, and grooved faces are no improvement over a perfectly smooth surface, with or without the thinnest kind of a gasket. The surfaces being smooth and perfectly faced have more to do with making tight joints than anything else. Bolts should all have finished hexagonal nuts and bolt holes should be spot faced.

71. Rules for Flanged Fittings.—*American* 1915 *Standard, Extra Heavy.*—1. Extra heavy reducing elbows carry same dimensions center to face as regular elbows of largest straight size.

2. Extra heavy tees, crosses and laterals, reducing on run only, carry same dimensions face to face as largest straight size.

3. Where long turn fittings are specified, it has reference only to elbows which are made in two center to face dimensions and to be known as elbows and long-turn elbows, the latter being used only when so specified.

TABLE 38.—STANDARD WROUGHT PIPE—TABLE OF STANDARD DIMENSIONS

Size (in.)	Diameters		Nominal thickness (in.)	Circumference		Transverse areas			Length of pipe per square foot of		Length of pipe containing 1 cu. ft. (ft.)	Nominal weight per foot		Number of threads per inch of screw
	External (in.)	Approximate internal (in.)		External (in.)	Internal (in.)	External (sq. in.)	Internal (sq. in.)	Metal (sq. in.)	External surface (ft.)	Internal surface (ft.)		Plain ends	Threaded and coupled	
1/8	0.405	0.269	0.068	1.272	0.845	0.129	0.057	0.072	9.431	14.199	2533.775	0.244	0.245	27
1/4	0.540	0.364	0.088	1.696	1.144	0.229	0.104	0.125	7.073	10.493	1383.789	0.424	0.425	18
3/8	0.675	0.493	0.091	2.121	1.549	0.358	0.191	0.167	5.658	7.747	754.360	0.567	0.568	18
1/2	0.840	0.622	0.109	2.639	1.954	0.554	0.304	0.250	4.547	6.141	473.906	0.850	0.852	14
3/4	1.050	0.824	0.113	3.299	2.589	0.866	0.533	0.333	3.637	4.635	270.034	1.130	1.134	14
1	1.315	1.049	0.133	4.131	3.296	1.358	0.864	0.494	2.904	3.641	166.618	1.678	1.684	11½
1¼	1.660	1.380	0.140	5.215	4.335	2.164	1.495	0.669	2.301	2.767	96.275	2.272	2.281	11½
1½	1.900	1.610	0.145	5.969	5.058	2.835	2.036	0.799	2.010	2.372	70.733	2.717	2.731	11½
2	2.375	2.067	0.154	7.461	6.494	4.430	3.355	1.075	1.608	1.847	42.913	3.652	3.678	11½
2½	2.875	2.469	0.203	9.032	7.757	6.492	4.788	1.704	1.328	1.547	30.077	5.793	5.819	8
3	3.500	3.068	0.216	10.996	9.638	9.621	7.393	2.228	1.091	1.245	19.479	7.575	7.616	8
3½	4.000	3.548	0.226	12.566	11.146	12.566	9.886	2.680	0.954	1.076	14.565	9.109	9.202	8
4	4.500	4.026	0.237	14.137	12.648	15.904	12.730	3.174	0.848	0.948	11.312	10.790	10.889	8
4½	5.000	4.506	0.247	15.708	14.156	19.635	15.947	3.688	0.763	0.847	9.030	12.538	12.642	8
5	5.563	5.047	0.258	17.477	15.856	24.306	20.006	4.300	0.686	0.756	7.198	14.617	14.810	8
6	6.625	6.065	0.280	20.813	19.054	34.472	28.891	5.581	0.576	0.629	4.984	18.974	19.185	8
7	7.625	7.023	0.301	23.955	22.063	45.664	38.738	6.926	0.500	0.543	3.717	23.544	23.769	8
8	8.625	8.071	0.277	27.096	25.356	58.426	51.161	7.265	0.442	0.473	2.815	24.696	25.000	8
8	8.625	7.981	0.322	27.096	25.073	58.426	50.027	8.399	0.442	0.478	2.878	28.554	28.809	8
9	9.625	8.941	0.342	30.238	28.089	72.760	62.786	9.974	0.396	0.427	2.294	33.907	34.188	8
10	10.750	10.192	0.279	33.772	32.019	90.763	81.585	9.178	0.355	0.374	1.765	31.201	32.000	8
10	10.750	10.136	0.307	33.772	31.843	90.763	80.691	10.072	0.355	0.376	1.785	34.240	35.000	8
10	10.750	10.020	0.365	33.772	31.479	90.763	78.855	11.908	0.355	0.381	1.826	40.483	41.132	8
11	11.750	11.000	0.375	36.914	34.558	108.434	95.033	13.401	0.325	0.347	1.515	45.557	46.247	8
12	12.750	12.090	0.330	40.055	37.982	127.676	114.800	12.876	0.299	0.315	1.254	43.773	45.000	8
12	12.750	12.000	0.375	40.055	37.699	127.676	113.097	14.579	0.299	0.318	1.273	49.562	50.706	8

4 Extra-heavy fittings must be guaranteed for 250 lb. working pressure, and each fitting must have some mark cast on it indicating the maker and guaranteed working steam pressure.

5. All extra heavy fittings and flanges to have a raised surface $\frac{1}{16}$ in. high inside of bolt holes for gaskets. Thickness of flanges and center to face dimensions of fittings include this raised surface. Bolt holes to be $\frac{1}{8}$ in. larger in diameter than bolts. Both holes to straddle center lines.

6. Size of all fittings scheduled indicates inside diameter of ports.

7. Square head bolts with hexagonal nuts are generally recommended for use.

8. Double branch elbows, side outlet elbows and side outlet tees, whether straight or reducing sizes, carry same dimensions center to face and face to face as regular tees and elbows.

9. Bull head tees or tees increasing on outlet, will have same center-to-face and face-to-face dimensions as straight fitting of the size of the outlet.

10. Tees, crosses and laterals 16 in. and smaller, reducing on the outlet, use the same dimensions as straight size of the larger port. Sizes 18 in. and larger, reducing on the outlet, are made in two lengths, depending on the size of the outlet as given in the table of dimensions.

11. For fittings reducing on the run only a long body pattern will be used. Y's are special and made to suit connections. Double branch elbows are not made reducing on the run.

12. Steel flanges, fittings and valves are recommended for superheated steam.

72. Fittings and Valves.—All flanged fittings and valves are made for three weights, standard for 125 lb. of steam, medium for 150 to 175 lb. of steam, and extra heavy cast iron for 250 lb. steam. They are also made in steel for superheated steam. There are also light fittings and valves in large sizes over 12 in. made especially for exhaust piping and condenser work. High pressure valves are generally outside screw and yoke, with beonze or steel stem and fittings.

Screwed fittings are made standard and extra heavy, and also of steel for superheated steam. Brass fittings are made in two patterns—one cast iron and one malleable iron—the latter being much lighter. The heavy-cast-iron pattern will stand any pressure liable to occur in any power plant practice. All valves are made of brass for sizes 2 in. and under and are all made in three weights—all over 2 in. have cast-iron bodies screwed or flanged. Flanged valves are generally called for on all sizes 4 in. and over, and sometimes as low as 3-in. As a rule, only steel can be used for superheated steam.

Couplings are just as good as flange unions in long lines of pipe and eliminate gasket joints although sufficient number should be provided to make disconnecting easy. The use of flange joints is considerably overdone in all classes of work. The size of pipe should have little to do with the use of flanges. The details should be made such that assembling and disconnecting can be accomplished with the minimum of labor. A good screw joint is better than a flanged joint where a gasket is in addition.

In all heating work, standard screwed fittings and flanged fittings may be used throughout. In water heating systems water fittings should be used. It is good policy to use short turn fittings on branches to radiators, due to cost and space. Therefore, they should be fairly large. Gate valves are always preferable to globe valves especially on water, due to friction. In cases where it is necessary for throttling, high pressure steam globe valves with nickel removable seats should be used.

73. Blow-off and Feed Pipes.—Blow off and feed piping for power plants should be extra heavy, not from the point of view of strength but from the fact that they are subject to corrosion more than any other portion of the system. In past years, brass was used, but the cost is excessive, and extra heavy pipe is a better paying investment even when the pipe has to be ultimately replaced. Cast-iron fittings and brass pipe make a good combination and this construction will resist corrosion permanently.

74. Pipe Covering.—All exposed surfaces of mains and heating pipes should be covered with insulating material to prevent loss of heat, especially if these pipes are located where the radiated heat will be of no service. The radiation from such surfaces is greater in proportion to the temperature difference than for cast-iron radiating surface. Cast-iron heating boilers

are generally covered with asbestos cement 1½ to 2 in. thick, wired on, and the whole given a coating of hard cement finish.

When hot water systems are used with a comparatively wide range in the temperature of the water, it is unnecessary to cover exposed riser pipes in the rooms as the water temperatures may be reduced if the pipes are left exposed. This means a saving of many thousands of dollars in large buildings of the commercial type where the covering amounts to nearly as much as the piping itself.

All coverings have for their insulating principle the cellular inclosure of air; the smaller the cells, the lighter the covering and the better the insulating qualities. Hair felt, magnesia carbonate, asbestos, diatomite, mineral wool, paper, and cork are some of the materials used for insulation. Enclosed stationary air is the very best insulator, therefore hair felt is one of the most efficient of the commercial coverings, but it deteriorates and chars under high temperatures.

Cork covering is also highly efficient and is extensively used on cold water and refrigerating pipe lines but is not favored for high temperatures. Mineral wool has been used extensively for underground mains. This is made from blast furnace slag blown into fine fibers. Due to the presence of sulphur, if any moisture gets near the covering and pipe, it eats the pipe surface very rapidly.

Asbestos and magnesia carbonate have come into almost universal use for pipe insulation due to their incombustility and excellent insulating qualities. Diatomite is a natural silicate composed of the minute shells of sea animals. It is also known as infusorial earth.

Where exceedingly high steam temperatures are used, magnesia or asbestos 2 and 3 in. thick should be used for covering because they are incombustible. Judgment should be used in selecting the material and thickness for pipe coverings, the temperature and permanency being the controlling factors. There is no advantage in using thick magnesia coverings on low temperature hot water mains. The heat loss with the pipe covered should be under 10 to 15%. Thickness and first cost should be considered in order to obtain this result.

Paper coverings built up with air cells are very economical for low pressure work, the paper being in the form of asbestos mill board. Wool felt is also economical.

Where long mains are run underground and the heat is entirely lost, the insulation of the pipe becomes very important and the most efficient is none too good. Underground drainage is also very important in this class of work.

Ordinarily, covering 1 in. thick is sufficiently heavy for use in buildings. For use in tunnels and trenches and for high pressure steam, at least 2 in. thick should be used. All pipe covering comes in molded sections about 3 ft. long made for the different commercial pipe sizes. The fittings are covered with a cement, finished smooth, and the whole canvas jacketed and painted with oil or water paint. Table 39 by J. R. Allen, gives the relative insulating qualities of different materials. Table 40 gives the losses for magnesia in B.t.u. for different sizes of mains with the last column of Table 39 (relative insulating value) the loss for any size pipe and covering may be readily determined in B.t.u.

TABLE 39.—RELATIVE CONDUCTIVITIES OF VARIOUS COMMERCIAL COVERINGS

(J. R. Allen)

Material of covering	Pounds of steam per hour per sq. ft. (covered pipe)	Ratio condensation of covered pipe to bare pipe	Thickness of covering (in.)	B.t.u. lost per sq. ft. per hr.	Relative insulating value compared with 1 in. hair felt and canvas
Moulded					
Asbestos	0.145	0.319	1.23	136	0.803
Magnesia	0.119	0.224	0.94	166	0.915
Magnesia and asbestos	0.125	0.300	1.12	118	0.879
Asbestos and wool felt	0.190	0.228	1.12	102	0.910
Wool felt	0.117	0.234	1.16	110	0.904
Wool felt and iron	0.134	0.269	....	125	0.828
Sectional coverings					
Mineral wool	0.097	0.193	0.94	91	0.952
Asbestos sponge	0.105	0.220	1.12	102	0.920
Asbestos felt	0.100	0.217	1.35	94	0.923
Hair felt	0.080	0.186	1.45	75	0.960
Non-sectional coverings					
2 layers asbestos paper	0.388	0.777	....	364	0.263
1 in. hair felt and canvas	0.070	0.150	....	68	1.000

Thermostat
H-1 *First floor supply*
E-2 *Second floor Exh.*
Pipe hanger
Pipe anchor
Expansion joint
Elbow-looking down
Elbow-looking up
Tee-looking down
Tee-looking down
U Pipe coil
Damper
Toilet exhaust
Kitchen exhaust
Vento-plan
Vento-elevation
Auto. air valve
Check valve
Diaphram valve
Angle valve
Safety valve
Hot water heater
R-R.F. *Register or Reg. face*
TG-BG. *Top or bottom grille*
Air washer
High pressure steam
High pressure drip
Low pressure steam
Low pressure return
Low pressure drip
Trap discharge
Column radiator-plan
Column radiator-Elev.
Wall radiator-plan
Wall radiator-elevation
Pipe coil-plan
Pipe coil-elevation
Supply duct or flue
Exhaust duct or flue
Supply register
Exhaust register
Trap
Gate valve
Globe valve
Water seal or Thermo. trap
Reducing valve
Piston pump
Fan
Motor
Engine

FIG. 33.—System of characters for use in drawing plans for power heating and ventilation.

TABLE 40.—HEAT LOSSES FROM MAGNESIA CANVAS COVERED AND UNCOVERED PIPE
(For 160-lb. pressure and 60-deg. air temperature. For any other pressure, use Unit "C." Other coverings can be compared by efficiency Table 39.)
(Babcock and Wilcox)

Size of pipe (in.)	Unit of loss	Thickness of covering in inches					
		Bare	½	¾	1	1¼	1½
2	A	597	149	118	99	86	79
	B	959	210	190	161	138	127
	C	3.189	0 770	0.613	0.519	0.445	0.410
3	A	876	206	172	137	117	106
	B	955	225	187	149	128	115
	C	3.08	0.723	0 602	0 479	0.413	0.372
4	A	1085	217	216	160	139	123
	B	921	210	164	136	118	104
	C	2.97	0.677	0.592	0.439	0.381	0.335
5	A	1326	301	247	193	166	146
	B	908	206	169	132	114	100
	C	2 93	0.666	0 546	0 425	0.368	0.323
6	A	1555	352	269	221	190	167
	B	897	208	155	127	110	96
	C	2.89	0 655	0.500	0.410	0.355	0.310
7	A	1780	400	304	250	212	188
	B	890	200	152	125	106	94
	C	2 87	0 643	0 490	0.402	0 345	0.303
8	A	1994	443	337	276	235	207
	B	883	196	149	122	104	92
	C	2 85	0 632	0 481	0 394	0.335	0.297
10	A	2168	549	416	337	287	250
	B	877	195	148	120	102	89
	C	2.83	0.629	0 477	0.387	0.329	0.287
12	A	2900	647	490	393	337	280
	B	871	194	147	118	101	84
	C	2.81	0.626	0.473	0.380	0.323	0.269

Unit "A" = B.t.u. per lin. ft. per hr.
Unit "B" = B.t.u. per sq. ft. per hr.
Unit "C" = B.t.u. per sq. ft. per deg Diff. per hr.

SECTION 2

WATER SUPPLY DATA AND EQUIPMENT

BY W. G. KIRCHOFFER

SOURCES OF WATER SUPPLY

1. Water in General.—Water is the most universal solvent known and for that reason is never found pure in nature. Falling in the form of rain, it absorbs dust and gases from the atmosphere; flowing over and through the earth, it absorbs organic and mineral matters. Pure water, as distilled in the laboratory, is composed of two elements, hydrogen and oxygen, in the proportion of two volumes of hydrogen to one of oxygen, and by weight, one of hydrogen to eight of oxygen. The term pure water, as loosely used in a commercial or domestic sense, usually means that it is wholesome and potable.

Surface waters usually contain organic matter as well as mineral matter, but ground waters, especially those of deep-seated origin, contain little or no organic matter, but always some mineral matter. The most common mineral matters found in well waters are the salts of calcium, magnesium, sodium, iron, silica, potassium, and aluminum, in the order named. When water contains much lime and magnesium salts, it is called hard. These matters in solution do not appreciably increase its weight until it becomes saturated like sea water, when it is about 2% heavier than distilled water.

Water occurs in three physical states—solid, liquid, and gaseous—and under proper changes in temperature and pressure can be readily transformed from one to the other. The mineral and organic content of water has very little effect upon the flow of water except as it roughens surfaces with which it comes in contact by forming incrustations, and thus decreases the velocity or, as in some extreme cases, decreases the diameter of the pipe.

Water is practically an incompressible liquid of constant volume except as it changes during the process of freezing or vaporizing. At 62 deg. F. it weighs 62.355 lb. per cu. ft., or 8.33 lb. per gal (U. S.).

2. Rainfall.—Rainwater, if obtained before reaching the surface of the earth, is the purest form of natural water, as is also snow. However, as soon as it has come in contact with the soil, it becomes contaminated owing to its solvent action. Ice is also a very pure form of natural water, as most of the substances in solution are forced out into the surrounding water during the process of freezing. Water that is contaminated bacteriologically, is purified to a

TABLE 1.—SEASONAL RAINFALL
(Inches per season)

Locality	Spring			Summer			Autumn			Winter			Monthly, (in. per mo.)	
	Av.	Min.	Max.	Av.	Min.	Max	Av.	Min.	Max.	Av.	Min.	Max.	Min.	Max.
New England and Central States	11.17	9.2	13.5	12.5	10.5	13.3	10.86	9.0	12.3	10.99	9.3	14.5	3	10
Southern and Gulf States	12.66	9.8	14.9	15.14	12.5	21.4	10.9	9.5	14.2	12.3	9.1	15.4	2	9
Upper Mississippi and Lake Region	8.9	6.5	11.0	11.4	9.7	12.4	8.41	5.8	9.7	6.44	3.1	10.3	1	5
Plain and Rocky Mountain Region	5.74	4.6	8.1	6.65	2.1	10.9	3.75	2.2	7.6	3.2	1.6	6.0	¼	6½
Western Plateau	2.1	1.3	3.4	3.1	0.8	5.8	2.3	1.3	3.5	2.95	2.0	3.5	¼	5¼
Pacific Coast States	8.2	6.2	9.8	2.3	0.3	6.9	8.16	3.5	10.5	16.6	11.9	21.0	½	12

great extent by the process of freezing, and ice that has been frozen for a few months is considered perfectly safe to use by some authorities even though its source had been polluted.

The amount of rainfall per minute, hour, day, month, season, or year varies greatly in all parts of the globe. Only a general notion can be given here of the amounts and variations in the United States. A knowledge of the rainfall in connection with buildings is useful where the supply is taken from a small stream or river; where rainwater is collected from roofs and stored in cisterns for domestic or industrial uses; and where the roof areas are so large as to materially effect the size of rain leaders (down spouts).

The annual rainfall east of the Appalachian Range is 40 to 50 in., well distributed throughout the year. West of this range and east of the Mississippi River it amounts to about 30 in., on the great plains 15 to 30 in., between the Rockies and Sierras, 10 to 20 in., and on the Pacific slope, 20 to 100 in. The higher limits are usually along the coast lines and about the Great Lakes.

The data given in Table 1 should be used only as a general guide. For more detailed information, see United States Weather Bureau reports and works on Hydrology.

3 Ground Water.—Ground water is a term applied to waters whose source is from the ground, whether from springs, seeps, or deep or shallow wells. Ground waters are always colder in summer and warmer in winter than surface waters, except those very deep-seated waters, such as boiling springs and geysers. The temperature of ground water below a depth of 50 ft. is the same as the mean annual temperature for the locality and does not vary from season to season. The temperature below this depth increases 1 deg. F. for each 60 ft. The outer crust of the earth to a depth of 50 ft. is influenced by the seasonal variations of temperature. From these facts it is possible to predict from what depth any water comes by comparing its temperature with the mean temperature for that locality. Ground waters are the most largely used sources of water for domestic purposes. A good potable water is one which is free from pollution and contains some mineral matter which makes it pleasing to the taste. Distilled water is very flat and insipid.

3a. Drilled Wells.—Drilled wells derive their water from rock or consolidated formations, such as sandstones, conglomerates, limestones, and trap rocks. The soft, caving formations above the rock are cased off with standard wrought-iron pipe or well casing, which should be driven firmly into the rock formation. Where possible it is preferable to extend the casing through any soft rock formation, such as shales lying above the water-bearing rock. In some cases wells are "grouted" from the surface of the water-bearing formation to the surface of the ground. In the case where the grouting is to be done on a new well, that portion of the well that must be grouted is drilled to a large diameter, say 12 to 20 in., and to a depth sufficient to prevent leakage, seepage, etc. The depth to be grouted is usually predetermined by a knowledge of the strata and should preferably extend to or near the top of the water-bearing formation from which it is desired to obtain the water. An outside casing must be used where the formations above the rock cannot be kept from caving long enough to permit of the completion of the work.

The hole at the bottom of the grout should be made smaller, of a size just large enough to receive the "liner" which should be seated firmly in the rock to a depth of at least 2 ft. The liner can be made of any grade of metal sufficiently strong to withstand handling and prevent collapse. The tops of both the outside and inside casings should reach the surface of the ground, or to the point where the water is to be taken off. In the case of flowing wells, the liner may be used as the discharge or suction pipe if pumping is done, and would be directly connected to the pump or horizontal pipe. The space between the two casings should be at least 2 in., but more is desirable. The space between the inner casing (liner) and the drill hole is filled with neat cement grout which is forced into the space by a hand pump.

The following apparatus is necessary: a line of 1¼-in. pipe, sufficient to reach within 10 ft. of the bottom of the space to be grouted, a hand or tank pump, and a half barrel or water-tight box of about the same size, in which the grout is placed. The 1¼-in. pipe is hung between the liner and the outside of the well and is so connected that it can be readily raised as the filling progresses. The grout is made of cement of such a consistency that it will pour readily and no sand is added to the grout while the pump is in use.

The yield of a well depends upon its diameter, the water-bearing strata intersected, the depth of the well (as effecting friction), and the ability of the pump to lower the water.

Where the water-bearing strata is of a uniform nature or texture, such as sandstone, the yield varies with the physical structure of the strata and directly with its thickness. When the water-bearing strata is not uniform, such as limestone and granite, the yield depends upon the number and width of the fissures.

The theoretical relationship of these quantities is difficult of expression and interpretation, but for rough estimates the empirical formula

$$Q = \frac{TL}{C}$$

holds approximately true for sandstone formations where the lowering of the water by pumping is not over 20 ft. and the diameter of the well is 6 to 10 in. In this formula

Q = yield in gallons per minute.
T = thickness of water-bearing formation in feet.
L = lowering of the water in feet.
C = a factor dependent upon the character of the formation.

The amount of water that can be taken from a well per unit of time depends very largely, in the case of small wells, upon the character of the pumping machinery. For example, a 6-in. well may have a large capacity due to a great depth of water-bearing rock pierced by the drill, yet with a single acting deep-well pump, it is difficult to secure much over 100 gal. per min. The size of a well should therefore be made amply large if drilled before the quantity of water required, the method of pumping, and the depth and character of the water-bearing rock are known or closely approximated.

The capacity of wells in limestone or traprock formations is difficult to predetermine owing to the fact that the extent and number of fissures to be encountered are unknown. The quantity of water will usually vary approximately with the thickness of the formation pierced and with the square root of the lowering. A good procedure is to test the well by pumping before its completion, and noting (1) discharge of test pump in gallons per minute, (2) the lowering of the water in feet, and (3) the thickness of the water-bearing strata encountered. Then from this data, predict the conditions which would take place if the desired quantity were obtained.

The capacity of a well does not vary greatly with the diameter so far as the ground resistance to flow is concerned. A large diameter is of advantage chiefly in reducing the velocity of flow within the well, thus reducing the friction and the advantage of placing a large pump.

These wells may be classed as either deep (non-flowing) wells or artesian (flowing) wells, depending upon whether the water in the water-bearing formation is under enough pressure to bring the water to the surface. In cases where the proposed well is within or near a well-established (developed) community, a careful study of the local conditions as to existing wells, will aid greatly in arriving at the proper diameter and probable depth. Quicksand, clays, shales, slates, and close-textured granites, should not be depended upon as sources of water for any purpose, not even a country residence. The total yield of ground water that may be collected varies from 0.1 to 0.5 million gal. per day per square mile, and at one locality, from 1 to 3 million gal. per day.

3b. Driven and Tubular Wells.—Driven and tubular wells secure their water from the loose formations above the solid rock, such as sand, gravel, or a mixture of these. Driven wells consist of a "point" attached to a screen, often called a "well point" or "well screen," which in turn is attached to several feet (as may be needed) of wrought-iron or steel pipe having a diameter to suit the "well point." These wells are seldom less than 1¼ or more than 4 in. in diameter. The points have openings 40, 60, or 80 meshes to the inch; the small sizes are usually 3 to 5 ft. long, and the larger sizes 8 to 60 ft. long.

Driven wells are usually relatively shallow, but in some cases have been driven to depths of from 400 to 500 ft. Driving to such depths is very liable to damage the screen. The amount of water to be obtained from such wells is very difficult to estimate for the principal reason that little or nothing is known about the character of the water-bearing material that is to be encountered. Even if the water-bearing strata is present, the possibility of getting the point entirely within it is quite an uncertainty. Where possible it is a much better plan to use a tubular well. This is put down in much the same way as the casing of a drilled well with the exception that a specially-designed shoe with a flange is used. When the water-bearing sand or gravel is reached, the point is dropped into the casing and is either driven below the end of the casing or the casing is pulled back to the top of the screen, or both processes of exposing the screen may be used. By this method much deeper and larger wells may be used, the point may be pulled up and examined, and a very definite knowledge of the water-bearing formation may be had by noting the character of the drillings and the behavior of the water levels when bucketing.

The amount of water to be obtained from wells of this kind varies greatly according to the porosity and coarseness of the sand or gravel. From tests of a large number of wells of this class it was found that with 60-mesh screen it was possible to secure ¼ gal. per min. per sq. ft. of screen surface per foot of lowering of the water in the well; that is to say, a well point having 5 sq. ft. of screen and a lowering of the water of 10 ft. would supply approximately 12½ gal. per min. Wells in coarse gravel will often supply very much more than this amount. Forty

wells located in coarse sand and gravel, yielded under test an average of 0.684 gal. per min. per sq. ft. of screen surface per foot of lowering, with a minimum of 0.45 gal. and maximum of 1.152 gal. per min.

Where the size of the sand grains is small or the porosity low, the capacity of this type of well can be greatly increased by packing the well screen in selected gravel. This can be successfully done by using a well casing 6 in. or more larger in diameter than the outside of the screen, and when the proper depth is reached, the well screen attached to pipe of slightly smaller diameter, is put in place. Then selected gravel ⅛ to ⅜ in. in size is placed about and for some distance above the screen. The large casing is then drawn by jacks and the well is complete.

In the same formation and in identically the same place, wells of this kind have been known to give 6 times as much water as wells having a 60-mesh well screen but without gravel. The screens used with the gravel-packed wells are usually coarser than 40 meshes per inch. Besides the common gauze mesh screens, there are a number of patented screens such as the Cook, Johnson, and Bowler.

3c. Dug or Open Wells.—Dug or open wells are usually relatively large in diameter, and shallow. The supply of water comes from the bottom and little or none from the sides unless it is excavated in rock formations. Wells of this kind are usually "curbed" with wood, brick, masonry, or concrete. The most successful manner of construction is to make a ring of concrete of the desired size, and after it has set sufficiently (3 to 4 days), lower it to the desired depth by excavating in the center. Such wells have been constructed 18 ft. in diameter by 60 ft. deep. Dug or open wells have the advantage of providing some storage of water, as well as a supply. Their capacity depends upon the physical characteristics and thickness of the water-bearing material, upon the lowering of the water, and upon the means provided for its entrance into the well. Metal screens may be placed in the walls near the bottom and the area of the water-bearing material, if of sand or gravel, may be covered with crushed rock or gravel to keep the fine sand from flowing in. The well should be properly covered to protect it from contamination.

The relative capacity of a well in the same formation, and with the same depth and extent of lowering, varies so far as ground friction is concerned, about as shown in the accompanying table, assuming that the water comes in through the sides and bottom of the well and that the yield of a well 1 ft. in diameter is unity.

Well diameter, feet	Units of capacity
2	2.101
3	3.173
4	4.214
8	8.378
20	20.660
40	40.980

From this table it is seen that the possible yield of a well of this type increases about as the diameter, but very much slower than the surface of water-bearing material encountered by the walls of the well. The yield of a well is often determined, not by the above consideration, but by the velocity of water at which fine sand may be carried into the well. This condition should be guarded against by properly designed screens in the walls of the well and by assorted layers of gravel placed over the bottom of the well wherever the water-bearing material is fine sand.

3d. Interference of Wells.—When any well is pumped for any considerable length of time at a given rate, there is a "cone of depression" established about it.

In cases of shallow wells, the surface of the water in the ground actually lowers, but in cases of deep-seated sources, the pressure against the impervious layer of earth restraining the water is lowered about the well.

When two or more wells in the same area and penetrating the same source are pumped simultaneously, their cones of depression overlap, and there is a marked interference of the flow of one well upon the other. This takes place as an actual decrease in the quantity pumped for a given lowering at each well, or, if the original quantity is pumped from each well, there will be an increased lowering of the water at each well over and above what there would be if each well were pumped separately.

This interference can be measured fairly accurately by pumping one well of a gang and noting the lowering of the water in the others of a gang, or special observation wells can be put down for this purpose.

If the lowering of the water due to pump any given time quantity Q from a given well be represented by a, and the lowering of the water in the other wells observed be represented by

b, c, d, e, etc., then, if all of the wells were pumped simultaneously at the same rate *Q* per well, the theoretical lowering of the water at each well will be the sum of these lowerings or *a-b-c-d-e-*, etc., depending upon the number of wells pumped.

If the observation, *b, c, d*, etc., were made on special observation wells of small diameter, then the summation given above would represent what the lowering would be if wells of adequate diameter and depth were put down at these same sites.

4. Springs.—Springs may be divided from an hydraulic standpoint into gravity and artesian (pressure) springs; and from a physical sense, into seepage, tubular, and fissure springs. Gravity springs are not confined between impervious beds, but flow because the ground-water surface is intersected by the surface of ground, as at the base of a hill or along a bank of a stream. Artesian (pressure) springs are confined between impervious beds, are relatively deep seated, and partake more or less of the characteristics of artesian wells. Such springs, if confined in a pipe or concrete basin, may be forced to rise several feet above the surface of the ground.

Seepage springs may be either gravity or artesian, but usually are of the gravity type and spread out over considerable area, as on a bench at the foot of a bluff along a river bank. This condition is usually accompanied by a soft spongy ground, abundant vegetation, and an oily scum due to decomposition of vegetable matter with the presence of iron or manganese. Many seepage springs are very deceiving as to the actual quantity of water flowing, owing to the relatively large area covered and apparent large quantity of water. Tubular springs are formed due to the solubility of some part of a rock formation or by the opening left by a decayed root. In limestone, the passages may extend for miles. These springs are often periodical—that is, fluctuating with the rainfall.

Fissure springs are always in rock formation and are usually artesian. They escape along bedding planes, joints, and cleavages in the rock formation and the waters are usually free from organic contamination, but are often highly mineralized. The requisite and qualifying conditions for the formation of springs are essentially the same as those for an artesian well; viz., a sufficient rainfall, a collecting area, a porous inclined bed of sand or rock with an opening for escape of the water at the lower edge, or in case of an overlying impervious stratum, an upward passage for the water.

Springs may be contaminated principally in two ways: (1) by direct wash of pollution into the water as it merges from the ground, and (2) by infiltration of polluted water on the catchment area. The first may be prevented by protecting the spring, and the second may be remedied if the exact location of the collecting area is known and the source of pollution removed.

5. Infiltration Galleries.—Infiltration galleries are really horizontal wells excavated below the level of the ground water. They are constructed so as to leave an open space within the ground water horizon into which the water can percolate through the porous sides or openings left for that purpose. They are often made of brick, stone masonry, or some kind of pipe, such as vitrified clay pipe. The supply that can be obtained from a gallery of this kind depends upon its length, depth below the natural water level, and upon the characteristics of the water-bearing material. This may vary from a fraction of a gallon to several gallons per foot of gallery. (A 12-in. vitrified pipe 300 ft. long laid in a medium sized sand supplied ⅔ gal. per ft. when the water level was lowered 6 ft.)

The Los Angeles Water Company has a vitrified pipe infiltration gallery 4500 ft. long which is reported to yield an average of 0.75 gal. per min. per ft. of gallery. The Crystall Springs Water Company, at about the same location, has 5368 ft. of similar gallery of vitrified pipe 15 to 24 in. in diameter, yielding 0.755 gal. per min. per ft. of gallery. At Grand Rapids, Wis., a 12-in. vitrified pipe gallery 960 ft. long, laid in extremely find sand of uniform size, yielded only 1/60 of a gallon per min. per ft. of gallery.

5a. Chemical and Bacterial Quality of Ground Water.—Ground waters from deep-seated rocks such as sandstones usually contain few bacteria. Water in limestone and other fissured rocks may carry pollution for miles. Shallow wells in loose formations may be easily polluted and should be protected for a considerable distance about the well. Bacterial analyses of water from new wells or similar works for the collection of ground water are misleading unless taken after several months of pumping due to the surface dirt remaining on the well casings and equipment.

Changing the draft on a supply may change its quality as determined by bacterial analysis. Pure waters, falling as rain on the ground, have great solvent power, and, hence, ground waters are highly mineralized and hard, as a usual thing; exceptions are where the country is entirely underlaid with a non-calcareous silt or sand.

6. Surface Waters.—The waters of lakes, ponds, rivers, and streams are very liable to be polluted and unfit for domestic use. Waters of this character, however, can often be used for

commercial and industrial purposes without treatment, or at the most, by filtration through pressure filters at rapid rates. In rare instances, waters from an extremely large lake or from a river flowing from an unpopulated territory, are safe without purification. Where a safe water supply is insufficient in amount for all purposes for a building, water for flushing of toilets, scrubbing, etc., can be taken from a surface water supply and the bubblers supplied from another source or a part of the surface water supply treated for this purpose. Before such a source of supply is chosen, or better still, before the site of the proposed industry or institution is chosen, the quantity and permanency of the supply should be investigated.

The factors affecting the flow of a stream are: drainage area, slope of surface, character of subsoil, temperature (evaporation), and rainfall Where the stream is large as compared to the demands of the industry, no detailed investigation might be necessary, but where the stream is small and varies in discharge with the seasons, a careful investigation should be made; also the character of the water, such as turbidity, color, and mineral and organic matter content, should be determined and compared with the needs of the industry.

Surface waters as a rule contain very much more organic matter and very much less mineral matter than do ground waters. These organic matters are largely of a nitrogenous nature and are difficult to remove when once passed into the nitrate form.

A conservative estimate of the quantity of water available from any stream would be 10 to 50% of the precipitation, depending upon the locality and nature of the stream. The rainfall should be taken for the average driest years. On streams where the minimum flow is likely to be less than or just equal to the demand, a small dam should be constructed across the stream to impound water to tide over the driest spells.

Ground versus Surface Waters.—Ground water compared with untreated and unfiltered surface waters has the advantage that its bacterial count is low, has little color, as a rule, is uniformly low in temperature, clear, and generally free from pollution, while surface waters generally are the reverse of all of these good qualities.

The relative disadvantages are that it is likely to be hard, often contains other minerals, as compounds of iron manganese and sodium, and the quantity is usually limited within any given area.

Works for the collection of ground water are usually subject to rapid depreciation—double pumping often has to be resorted to—and are inefficient as compared with pumping methods from surface supplies, and prediction of an adequate supply from any given area is more or less a matter of speculation.

PURIFICATION OF WATER

7. Impurities of Water.—Water may be considered to be impure from either a chemical or a sanitary standpoint. Mineral matters contained in waters, if in sufficient quantities, may interfere with steam making and industrial uses, and if it contains large quantities of alkalies, it will even be unfit for domestic use. The impurities which we are more concerned about are those of a sanitary nature and are of organic origin. A water may be ever so clear and of excellent taste and yet contain thousands of disease-producing germs.

8. Sources of Pollution.—A polluted water is one which contains the wastes from human habitation. It may not necessarily contain disease-producing germs or matters in which they are usually found, but may contain such other wastes as to make the water unwholesome. "Contaminated" is sometimes used synonymously for the word "polluted," but it is stronger and means that the water has and does contain wastes which might cause disease or disorders. Besides the sewage carried away from buildings by sewerage systems, there are other sources of pollution, such as outhouses, slop drains (from kitchens), industrial wastes, decaying animal matter, and drainage from farm buildings and yards. The discharge from sewerage systems usually pollutes only surface waters, whereas the other sources pollute ground waters as well.

If a water supply must be taken from a surface water, it should be taken, in case of a stream, far enough above the outlet of the sewer to be sure that none of the sewage will be drawn into the intake, and in case of a lake or other body of water, the intake should be in deep water and removed as far as practicable from the sewer outlet, even though the sewage be treated or purified.

In the case of ground waters, it is more difficult to trace sources of pollution to a water supply. In general, ground waters flow in the direction of the slope of the ground, *i.e.*, into ravines, dry runs, and valleys. In all cases the source of water supply should be located so that the surface drainage will be away from, rather than towards the well, spring, or point on stream where the supply is taken.

9. Aeration.—The usual process of purifying water by aeration is to discharge it into the air so as to break it up into a fine spray or a thin film. The process is used to oxidize organic matter, remove gases, such as hydrogen sulphide, and carbonic acid gas, and odors produced by aquatic vegetation. It is also used in some cases as a part of the process of removing iron and manganese.

10. Sedimentation.—Many surface waters, owing to the nature of the ground over which they flow, contain large quantities of suspended matter which may or may not be of a polluting nature. Many rivers flowing through a country where the surface material is largely clay, contain large quantities of finely divided clay in suspension. The process of sedimentation either natural or artificial, is used to remove as much of this material as possible. In some cases for industrial use, it is the only process needed, while in other cases it is a preliminary process to filtration, coagulation, or both.

Sedimentation is divided into two types, intermittent and continuous. The first gives no better results than the second, but in some cases for industrial use, it is more convenient where the use is intermittent, to fill a tank or basin, let it stand from 12 to 24 hr., and then draw off the clarified water. Continuous sedimentation is the most satisfactory process where large quantities are needed continuously. As a preliminary process to coagulation or filtration, the period should be from 6 to 24 hr., depending upon the fineness of the sediment and upon the relative cost of sedimentation basin and subsequent process. Fuller says that the economical limit of plain sedimentation is 24 hr., during which time 75% of the suspended matter is removed.

For large impounding reservoirs where the water is to be used for a domestic supply without further treatment, the period of sedimentation should be three or more days, depending upon the fineness of the sediment. The percentage of removal is greatest when the amount of suspended matter is greatest. Twelve hours subsidence removes about 33%, and 24 hr. removes from 59 to 83%. The process should take place in a basin or tank of proper size for quantity to be treated. The inlet and outlet should be made so that the velocity will be a minimum; baffles should be used to prevent currents from forming; and screens should be provided to keep out leaves and floating matter from entering the outlet.

11. Chemical Treatment.—Chemical treatment may be used for the following purposes: (1) removal of bacteria and polluting organic matter; (2) removal of suspended matter—clay, etc. (producing turbidity), and vegetable compounds (producing color); and (3) removal of iron, manganese, and the salts producing hardness.

This treatment may be used with or without sedimentation depending upon the nature of the case. For (2) it is necessary in all cases to provide some sedimentation for effective work. The coagulants used for purposes (1) and (2) are sulphate of alumina, sulphates of iron, calcium oxide or hydrate, and sodium carbonate. Sulphate of alumina is most commonly used alone where the alkalinity is high enough to produce the necessary floc or precipitate. The amount of the chemicals used varies from a fraction of a grain to 6 or 8 grains per gal. depending upon the character of the water. Little work along these lines should be attempted by the architect or engineer without the aid of a chemist.

12. Filtration—*Action and Function.*—Sand and gravel have been found to be the most satisfactory materials to use in the process of filtration. When water is passed through a layer of these materials, a large portion of the suspended matter, bacteria, and color is removed. Even colorless organic matter in the colloidal form is partially removed. The function of the filter is to strain out the bacteria and suspended particles and this function is performed not only by the sand but also by the very organic matter which it is sought to remove, the organic matter forming a sort of gelatinous substance around the sand grains. That organic matter does act in this manner is shown by the fact that a filter is more effective after it has been in operation for some time.

There are two methods of filtration in common use: (1) the slow sand process, and (2) the mechanical or rapid sand process. In (1), the water is passed through a bed of sand and gravel 3 to 5 ft. thick to a system of underdrains at an average rate of 1.6 million gal. per acre per day. This process is seldom used for small installations such as would be used in connection with a building. In (2), mechanical filters operate at much higher rates, 100 to 200 million gal. per acre per day. The rapid filtration of water is distinguished from slow filtration, not alone by the difference in the rates of flow, but by several other features, such as the formation of the colloidal coating, which naturally differentiates the two general methods of purification.

Mechanical filters may be divided into gravity filters and pressure filters. Gravity filters as the name implies, signifies that the water flows through the filter by gravity.

Essentials of Rapid Sand Filters.—The simplest form of a rapid sand filter must have the following essential features:

(*a*) A suitable underdrainage system for the collection of the filtrate and for distributing the wash water over the entire area. Gravel, pipe grids, nozzles, and even porous concrete have been used for this purpose.

(*b*) A thick layer (about 2 ft.) of selected uniform sand as a filtering medium.

(*c*) Wash troughs spaced about 5 ft. apart above the sand to carry away the dirty wash water when filter is being backwashed.

(*d*) Pipe connections and valves for controlling inlet water, filtrate, wash water, dirty water to sewer, and re-wash for wasting filtrate.

(*e*) A control table hydraulically operated or hand-operated valve stems for controlling the water.

Gravity filters are usually arranged in two rows, with a common water supply pipe, valves, wash-water pipes, rate of flow-controlling apparatus, gages, etc., in a pipe gallery between the rows. These filters are in round wooden or steel tanks (old type) or in square concrete basins (new type). The clear water basin is usually placed beneath the filters. The wash water required for mechanical filters is 5 to 7 gal. per min. per sq. ft. of filter area. The head required for washing is 30 ft. or more depending on the type of strainer used at base of filter. The amount of water used for washing per day is equal to a column of water 5 or 6 ft. high over the entire area of the filter. A gravity filter has an advantage over a pressure filter in that it is easier to observe every step in the filtering operation, and it is possible to examine the condition of the sand at any time without shutting down the filter.

Pressure filters are closed cylinders or tanks of steel in which is placed a bed of sand or crushed quartz and through which the water is forced under pressure (see Fig. 1). Other filtering materials for special purposes, such as charcoal, coke, or zeolite are sometimes used. The strainer system also acts as a distributor for the wash water during the cleaning of the sand bed. During the washing process compressed air is often used.

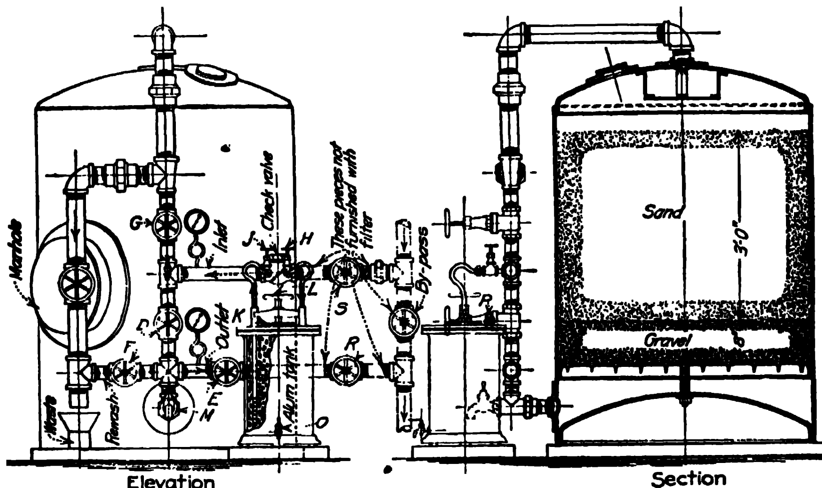


Fig. 1.

TABLE 2.—TRADE DATA ON AMERICAN WATER SOFTENER CO.'S WOOD TANK GRAVITY FILTERS

Diameter (feet)	Area (sq. ft.)	Capacity (gal. per min.)	Size inlet (inches)	Weight* (pounds)	Appox. cost per 100 gal. per min. capacity
6	28.27	56	3	12,500	$1400.00
8	50 26	100	4	22,250	1150.00
10	78.54	157	4	34,500	975.00
1	113.10	226	5	50,700	840.00
14	153.94	307	6	67,700	760.00
15	176 71	353	6	78,700	725.00
17	226 98	453	8	101,400	700.00

* Total weight includes sand and gravel.

Table 3.—Data on Typical Pressure Filters

Diameter (inches)	Area (sq. ft.)	Inlet and outlet pipes (inches)	Capacity (gal. per min.)	Approximate shipping weight (pounds)
24	3.1416	1½	6-9	1,150
30	4.9087	1½	10-15	1,800
36	7.0686	1½	14-21	2,000
40	8.72	2	17-26	2,275
42	9.6211	2	19-29	2,400
48	12.5666	2½	25-37	2,875
50	13.64	2½	27-41	3,225
60	19.635	2½	39-59	4,250
72	28.27	3	56-84	5,300
78	33.183	3	66-99	6,300
84	38.485	4	78-115	7,700
96	50.26	4	100-150	11,350

The above capacities are conservative. Use minimum capacities for muddy waters. Where maximum capacities are exceeded, resistance will increase, the filter will require washing more frequently, and the filtered water will not be of as good quality.

Pressure filters, where no preliminary treatment is required, are used extensively for the reason that they are simpler and cheaper than gravity fibers. Filters treating water for industrial purposes should always be provided with a by-pass so water can be supplied direct in case filter is cut out for repairs. The bacteria removing efficiency of mechanical filters is approximately 95%.

13. Rain-water Filters.—Besides its use in the laundry where it is desired on account of its softness, rain water, when properly aerated and filtered, makes a wholesome beverage. It should, however, be caught and stored so as to preserve its original purity. The present methods of collection and storage in most cases are bad. Every roof is foul with excrements of birds, dead insects, leaves, dust, etc , all of which are washed into the cistern. The first part of every rain should be turned off until the roof is washed clean. There are several automatic devices for this, but few are used. It will not in most cases be economical to attempt to filter the water as rapidly as it may come from a roof. It will be preferable and cheaper to first store the water in a tank or reservoir of wood, masonry, or slate, which should be located above the ground if possible. From such a reservoir the water should be led to the filter which should consist of sand and gravel, similar to the above described gravity filters.

The filter should be large enough to care for the average daily consumption, or at least large enough to filter the contents of the storage tank before another rain fills it. The rate of filtration should be between 50 and 150 gal. per sq. ft. per day; a layer of sand 2 ft. deep is sufficient. If desired, charcoal can be added to free the water of undesirable taste and smell. When the filter becomes clogged, it should be scraped to remove the sediment, but the sand and gravel below should not be disturbed except at long intervals, or when the filter ceases to work due to severe clogging.

The filtered water should be stored in a clean, tight, and well-protected cistern or underground reservoir, from which the supply for domestic use is taken. Where the use of water may be largely for mechanical or industrial purposes, there could be two cisterns, one for filtered and one for unfiltered water. In this way the storage tank and filter could be made smaller. Upward flow filters built in a part of a cistern are worse than useless, as the pressure of the water will force a passage through in one or more spots and thus defeat the purpose of filtration. Also, galvanized-iron receptacles attached to down spouts and filled with charcoal, are only strainers and *do not* purify the water.

If the roof tributary to the filter plant has an area of 1000 sq. ft. and the ordinary maximum rainfall is 2 in. per storm, then the capacity of the storage tank should be 1250 gal. and the filtered-water cistern should have a capacity sufficient to tide over dry spells. A cistern of 10,000-gal. capacity (for dimensions see Table 39, p. 1279, will supply 400 gal. per day for about one month.

14. Removal of Iron.—If iron occurs in water to the extent of 0.2 to 0.3 parts per million it will cause little or no annoyance. In some cases 0.5 parts per million have given no trouble. Where iron occurs in the ferrous condition as hydrate, bicarbonate, or sulphate, its removal is comparatively easy by aeration and filtration, but where it occurs as a chloride or nitrate or in the presence of manganese, organic matter, vegetable acids, or in a polluted water, its removal is difficult. Iron may be said to exist in waters of three classes: (1) Those which begin

to precipitate on exposure to air, iron in hydrate form; (2) those which will hold iron in solution indefinitely even when aerated, iron usually combined with vegetable acid and appearing in a colloidal form; (3) waters which contain iron in both forms and therefore deposit a part, but not all, of the iron contents after aeration.

The principal methods of treatment for class (1) are: aeration, sedimentation, filtration, coke contact, sprinkless, and filtration through sand. For class (2): aeration, coke contact, sand filtration, chemical treatment, sedimentation, and filtration. For class (3): a hypochlorite with filtration through chemically treated sand beds, or filtration through aged beds of sand.

Iron-bearing waters are of the greatest annoyance in the laundry where they stain the clothes. Waters of the first class readily give up their iron when heated so that a simple pressure filter will remove the difficulty to a large extent if not overtaxed.

Iron also causes trouble by clogging mains and service pipes due to the presence of the iron organism, crenothrix, which has the ability of causing a deposit of iron to form on the inside of the pipes.

15. Removal of Manganese.--Waters containing manganese are more difficult to treat than those containing only iron. Where the same processes are effective, they react much more slowly. In a water containing both iron and manganese, the iron will be found deposited near the source while the manganese will be found on the outskirts of the system and in dead ends. Manganese is no doubt a much more troublesome element than is generally supposed. It often gives to the water a milky appearance due to its colloidal form. When present with iron, organic matter, carbonic acid, and vegetable acids, it is a most difficult element to remove. Salts of sodium, especially a hypochlorite, seems to have the quickest and greatest effect on it when in this condition.

The higher oxides of manganese appear to have a very favorable effect on the removal of those of a lower order, so that if water containing manganese is applied to a filter in which higher oxides have been precipitated, a large percentage of the manganese in the water will be removed. Such a condition can be brought about by treating the filter with manganese sulphate, sodium hydroxide, and a hypochlorite, or by letting the filter become automatically coated as it will do in most cases if not disturbed. The rate of filtration for the removal of iron and manganese varies greatly with the character of the water, but would generally come between 1000 to 2000 gal. per sq. ft. of surface of filter per day.

16. Causes of Incrustation.—Incrustation of steam boilers, water heaters, furnaces, coils, etc., is caused by deposition of the following: suspended matter; deposed salts from concentration; carbonate of calcium and magnesium by boiling; suphates and chlorides at temperature above 270 deg. F.; manganese at high temperature; and lime, iron soaps, etc., formed by saponification of grease.

17. Effects of Incrustation.—Incrustation reduces efficiency of steam boilers, water heaters, furnace coils, and siphon jet closets; causes boiler plates to become overheated and distorted; and in some cases, causes failures to occur. Hot-water heaters, especially of the coil type, and furnace "backs" or coils become so incrusted as to stop circulation. Hot water pipe systems become incrusted to such an extent as greatly to reduce their capacity, if not clog them entirely.

Means of preventing incrustations are: filtration; blowing off boiler; use of internal collecting apparatus, or devices for directing the circulation; heating feed water keeps scale caused by temporary hardness from entering the boiler; use of boiler compounds; introduction of zinc into the boiler; water softening. Other remedies for these troubles will be found in Art. 19.

18. Hardness of Water.—Waters are said to be hard because of their action upon the skin of the body and because of their neutralizing effect on soap. Hardness is of two kinds: (1) that caused by the bicarbonates of calcium, magnesium, and iron, which is called temporary hardness and can largely be removed by boiling; and (2) that caused by the sulphates, chlorides, nitrates, and silicates of calcium and magnesium, which is called permanent hardness because boiling not only does not remove it, but, on the other hand, tends to increase it. The sulphates, chlorides, etc., form much harder scale than the bicarbonates. Hardness is measured by grains per gallons, parts per 100,000, and in parts per million in equivalent calcium carbonate.

Waters have been classified as follows in parts per million:

0–50	Very soft
50–100	Fairly soft
100–150	Medium
150–200	Moderately hard
200–300	Hard

A water containing 0 to 70 parts per million of equivalent calcium carbonate is considered a very good boiler water; 70 to 150, good; and 150 to 250, fair.

18a Advantages of Soft Water.

1. The added comforts experienced by a change from hard to soft water cannot be appreciated until after the change is made.

2. Manufacturing interests appreciating the value of soft water will more readily locate in a community having soft water than in one having hard water.

3. Waters of questionable quality or liable to an occasional pollution are made safe by the action of the lime on the intestinal and typhoid organisms.

4. The lime treatment not only removes hardening salts from the water but also removes iron and absorbs color due to organic matter.

5. It renders the soap used more effective and prevents incrustation of steam boilers, hot-water pipes, and heating coils.

19. Water Softeners. *Lime-Soda-Ash Process.*—Water may be treated with chemicals to remove its hardness, or it may be passed through a bed of mineral under pressure.

Temporary or carbonate hardness may be removed by the use of lime (calcium oxide), and permanent or sulphate hardness may be removed by the addition of sodium carbonate. The entire hardness of any water cannot be removed by the lime-soda-ash process, but it can be reduced to a point where it is not objectionable.

The process can be operated on the continuous-flow method or on the fill-and-draw method. In any installation there should be some method of accurately measuring the chemicals as they are fed into a given quantity or rate of flow of water, as, for instance, a weighing device, or a dry chemical feeder. The water and chemicals should then be mixed gently for 20 to 30 min. and then settled for 4 to 7 hours before filtering through sand.

The American Railway Engineers and Maintenance of Way Association estimate as follows the amount of chemicals required to remove 1 lb. of incrustating matter:

Incrustating substance held in solution	Quantity of reagent (pure)
Calcium carbonate	0.56 lb. lime
Calcium sulphate	0.78 lb. soda ash
Calcium chloride	0.96 lb. soda ash
Calcium nitrate	0.65 lb. soda ash
Magnesium carbonate	1.33 lb. of lime
Magnesium sulphate	0.47 lb. lime plus 0.88 lb. soda ash
Magnesium chloride	0.59 lb. lime plus 1.11 lb. soda ash
Magnesium nitrate	0.38 lb. lime plus 0.72 lb. soda ash

Pressure Water Softeners—Zeolite Type.—Water which has been freed from suspended and organic matter, iron, and other interfering elements, or water which contains only small quantities of these elements, can be softened by passing it through a bed of natural or artificial zeolite 20 to 40 in. thick. The apparatus is similar to a pressure filter (see Fig. 1). When the softener has passed a stated quantity of water, depending on its hardness, it has to be shut down, drained out, and filled with a 10% brine solution. The period of contact is usually 12 to 16 hr., depending on local conditions. The amount of salt required to regenerate the zeolite, according to some authorities, is 3⅓ to 6 lb. per 1000 gal. of water for each 100 parts per million of equivalent calcium carbonate. This process is the only one known that reduces the hardness to zero when properly cared for. The method, however, is not suitable for boiler water, as it leaves the equivalent of sodium carbonate which will cause foaming.

Some of the advantages of the zeolite process are:

1. It is the only practical process by which water of a zero hardness can be produced on a large scale.
2. Only one chemical is needed (common salt).
3. Variations in the hardness of the raw water are automatically taken care of.
4. There is no sludge to be removed.

Disadvantages:

1. Cost of operation is higher than with lime and soda ash.
2. Water to be softened must be perfectly clear, for if it contains turbidity, the pores of the zeolite become clogged.
3. The zeolite softened water contains residual sodium bicarbonate and if used in boilers may cause trouble by foaming.

TABLE 5.—TYPICAL ZEOLITE WATER SOFTENERS—VERTICAL PRESSURE TYPES

Diameter, inches	Height, inches	Floor space, feet × feet	Weight complete, pounds	10-hour capacity* based on water of 10-gr. hardness, gallons
12	60	2 × 2	750	775
24	65	3 × 3	2,500	3,560
36	75	3 × 5	3,800	8,000
48	80	4 × 7	9,000	14,000
60	82	5 × 7	15,000	23,000
72	86	6 × 9	20,000	32,000
84	90	7 × 10	26,500	43,750

TABLE 6.—TYPICAL ZEOLITE WATER SOFTENERS—HORIZONTAL PRESSURE TYPES

Diameter, inches	Length, feet	Floor space, feet × feet	Weight complete, pounds	10-hour capacity* based on water of 10-gr. hardness, gallons
96	12	8 × 17	60,000	108,000
96	14	8 × 19	80,000	127,000
96	16	8 × 21	100,000	115,0000

* On water of other hardness, capacity is inversely proportional to total hardness in grains per U. S. gallon. The salt consumption is approximately ¾ lb. per 1000 gal. per grain hardness.

Lime-Zeolite Softening Process.—Where an extremely hard water containing much non-carbonate hardness is to be softened, it is of advantage, in point of cost of operation, to combine these two processes into the lime-zeolite process.

The water is first treated with sufficient lime to remove all but about 50 p. p. m. of the carbonate hardness and the magnesium salts; then it is passed through a bed of zeolite either by gravity or by pressure.

By this method, a water of any degree of softness from zero up can be produced. This is accomplished by passing only a portion of it through the zeolite filters and the balance through a sand filter and then mixing the two portions.

20. Interpretation of Bacterial Count.—The fact that a water may contain a large number of bacteria means little unless some knowledge is had of their kind and characteristics. There are numerous varieties of water forms which are perfectly harmless if taken into the system. On the other hand, a very small number of typical sewage bacteria found in a majority of samples, especially in 1-c.c. samples, should be looked upon with suspicion. Colon bacillus appearing in a few samples of 10 c.c. with no other characteristics of pollution should not be taken as indicative of an unsafe water. Water that is grossly polluted will usually show large numbers of bacteria growing on both gelatine and agar together with liquifiers, gas producers, and the presence of colon bacillus in 1-c.c. and 10-c.c. samples. Waters that are occasionally polluted will show some or all of these evidences a majority of the time. Therefore, the purity of a given water should not be determined upon a single analysis when that analysis reveals the fact that there is a possibility of contamination.

21. Disinfection and Sterilization.—A water supply is sometimes found where there is no objectionable organic matter present, but which may be subject to contact with pathogenic bacteria. In such cases no treatment such as filtration is necessary, but it is advisable to treat the water with a germicidal agent such as calcium, sodium hypochlorite, or liquid chlorine. These oxidizing agents may be applied in amounts varying from 0.2 to 0.3 parts per 1,000,000 of available chlorine without detriment to the water.

Where a water is pumped from a source, such as above described, direct to a distribution system, it is customary to apply the dose in the suction pipe, the rate of application being controlled by the rate of pumping.

WATER CONSUMPTION

22. In General.—The quantity of water required for any use varies greatly, especially so in residences, where leakage, waste, quality, and temperature are influencing factors. Consumption in cities and villages is usually reckoned on the "per capita" basis and includes all uses, such as domestic, fire, sprinkling, manufacturing, and municipal In 111 cities with a population of 25,000 or over, the consumption was as follows: maximum 324, average 105, minimum 31 gal. per capita per day. In 76 cities with less than 25,000 population, the consumption was: maximum 149, average 61, minimum 10 gal. per capita per day. Per capita rate in cities usually lies between 60 and 270 gal. per day with an average use of about 100 gal. per day.

23. Residences.—The quantity of water used in residences must necessarily be less than the above averages as it includes only household use, lawn and garden sprinkling. The minimum and maximum consumption in a residence is 42 and 151 % of the average, respectively. Minimum usually occurs from 3 to 4 A.M., average between 7 and 9 P.M., and maximum from 9 to 10 A.M. This will vary according to the number of fixtures, leakage, careless use, etc., but with all of the uncertainties, the average residence consumption will be from 15 to 50 gal. per capita per day.

From the experience of the army cantonments in this country, it was learned that 30 gal. per capita per day is sufficient for all domestic needs, inclusive of sewer flushing, but exclusive of lawn sprinkling and water allowed to run to prevent freezing.

24. Factories and Industries.—The consumption will vary greatly with the nature of the work involved, with the availability of the supply, and with the number and character of the plumbing fixtures in use. No hard and fast rule can be laid down for this class of consumption. In Table 7 are shown some data that will give a rough notion of the consumption that might be expected.

TABLE 7.—CONSUMPTION OF WATER BY FACTORIES AND INDUSTRIES
(Based largely on meter reading)

Character of plant	Min.	Max.	Average
Average eight factories, engines, machines, and supplies per employee per day	24	78	57
Ordinance plants per employee per day	12	33	24
Gasoline engines per employee per day	57		
60 ton sulphite pulp mill per ton			
Acid making			2,625
Cooling gases			5,664
Washing blow pits			4,220
Pumping out blow pits			34,496
Wet room			63,184
Shipped away with pulp			500
Waste			1,200
Total	40,000	150,000	111,889
Tanning hides per hide	17	50	33
Coal mine waters per ton coal	1,200	2,400	
Coal gas per ton coal used	104	136	125
Textile trades:			
Bleaching per lb. of cloth	15		
Bleaching per lb. cotton waste	24		
Wool washing per lb	1	2.24	
Yarn scouring per 100 lb	26		
Woolen pieces per yd	8 33		
Mixing concrete per cubic yard	50	150	

25. Apartment Houses.—The consumption in apartment houses is not greatly different from what we would expect to find in residences, except that there is a comparatively small amount of laundry work done, and usually no lawn or garden sprinkling. The meter readings of nine of these apartment houses give an average of 50 gal. for this type of consumption, with a minimum of 35.4 and maximum of 75 gal. per capita per day. The meter readings of 13 apartments, some having special uses, give a minimum of 35.7 gal., an average of 74.4 gal., and a maximum of 181 gal. per capita per day.

The size of the apartment building, *i.e.*, number of separate apartments, does not influence the per capita rate. In large cities the consumption appears to be greater than in small cities. Municipally owned plants with low rates tend to promote lavish use and waste of water as compared with privately owned plants. Where water is used for special purposes, such as pumping air for thermostat operation, water for cooling, and for ice machines, the consumption may run from 75 to 180 gal. per capita per day. In Boston, Dexter Brockett found that the average consumption of 339 apartment houses was 35.6 gal. per capita per day and that the best class used 59 gal., first class, 46 gal., moderate class, 32 gal., and the poorest class, 16.6 gal. per capita per day.

26. Schools.—The average consumption (meter readings for 6 mo.) of 15 schools was 22 gal. per capita per day, the minimum of 12 public schools was 8.5 gal., and maximum, 45 gal. per capita per day. Three parochial schools gave a minimum of 4 gal. and a maximum of 24 gal. per capita per day. The number of pupils in a building did not seem to influence the rate of consumption.

Schools where domestic science was taught and shower baths used, show a minimum of 13 gal., a maximum of 45 gal., with an average of 30 gal. per capita per day, whereas in schools where neither domestic science was taught nor shower baths used, the minimum was 8.5 gal., maximum 39 gal., with an average of 19 gal. per capita per day.

27. Milk Condenseries.—Condenseries use from 2 to 3 gal. of water per lb. of milk with a possible average of 2.65 gal. per lb. of milk.

28. Institutions.—Institutions, especially those of state or public ownership, are lavish users of water, as a rule. The average water consumption for 37 institutions was 104 gal. per capita per day, 20 gal. minimum, and a maximum of 310 gal. Of this number of institutions, a Y.W.C.A. camp, a children's home, and a university were the minimum users of water, with a consumption of 20 to 25 gal., whereas a state hospital used the greatest amount—*viz.*, 310 gal. per capita per day.

The minimum consumption for 15 state hospitals and asylums was 50 gal. per capita per day, a maximum of 310 gal., with an average of 63.55 gal.

29. Variations in Rates of Consumption.—The consumption of water varies with the seasons, temperature, day of the week, and hour of the day. Seasonal fluctuations vary from a minimum of 75 % to a maximum of 125 % of the yearly average. Effect of temperature is shown by a record from Detroit, Mich., on an extremely cold day when the consumption for the entire day was 150 % and over, of the yearly average. This excess was waste and was done to prevent freezing. On an extremely hot day in the same city, the consumption went up to 175 % of the average. Sunday consumption was found to be from 50 to 85 % of the daily average. Fig. 2 illustrates the hourly variation in consumption in per cent. of the average daily rate for several classes of consumption. The curves represent average conditions in American cities.

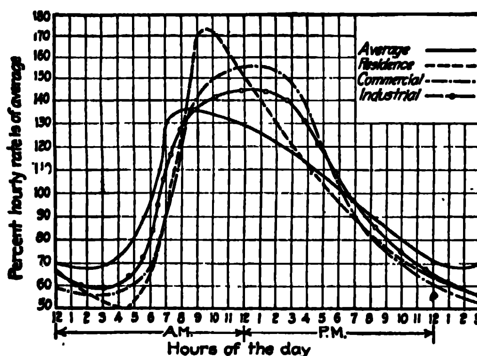


Fig. 2.

C. M. Saville, Superintendent of Waterworks, Hartford, Conn., measured the maximum rate of consumption of a number of consumers of different classes, a partial list of which is given in Table 8. It will be noted that the maximum consumption of a tenement house occupied by 110 people, an apartment occupied by 40 people, and a family of 6 people is nearly equal in amount. However, the duration of these maximums was much greater for the larger users, being 3 min. for the residence and 70 min. for the apartment house.

TABLE 8.—MAXIMUM OBSERVED RATES OF CONSUMPTION IN HARTFORD, CONN.
(Journ. N. E. W. W. Ass'n. Dec., 1918)

Character of service	Number of fixtures	Maximum observed rate, (gal. per min.)	Size of meter needed (inches)
1. 56 rooms, 150 people	94	52.[illegible]	1½
2. Market	1*	150.0	2
3. School, 460 pupils	94	150.0	2
4. Bank	1*	135.0	2
5. Hotel	202	135.0	¾
6. Hotel elevator	1*	225.0	3
7. School, 10 room, 15 teachers, 500 pupils	56	45.0	1
8. Tenement block, 110 people	100	9.0	¾
9. Industry, 1000 employees, hundreds of customers	44	32.25	1½
10. 60–2 room apartments, 120 people and department store	135	93.75	1½
11. Laundry	15	225.0	3
12. Residence, 6 people	15	10.0	¾
13. Apartment, 12 suites, 40 people	55†	9.6	1

* Elevator lift. † Estimate.

30. Meters.—A meter should be selected for a given service so that the ordinary rate of flow of water will be approximately the rate at which the accuracy of the meter is a maximum. Too often the selection of the size of a meter is governed by the desire to cut down the loss of head between the main and the faucet, than it is on the rate of flow in the service pipe. Under such conditions, the service rendered does not come within the limits of accurate registry of the meter, and as a result the meter greatly underregisters. To meet these conditions, with a view to economy as well as efficiency, Saville says it is desirable to consider:

1. The installation of larger service pipes instead of larger meters.
2. Proper provision in the house-piping system, to meet the demands of modern plumbing, instead of installing larger meters. A large-sized riser pipe, acting as a house standpipe, where flushometer fixtures are installed, might give a better service than could be obtained by use of a larger meter.
3. The selection of meters properly designed for the particular use to which they are to be put. So far as accuracy of registration and durability goes there seems little to influence choice between any of the meters now put on the market by the half-dozen or more reputable manufacturers of water meters. So far, however, as loss of head is concerned, meters of different makes now on the market show considerable variation.

A meter should be set where it will not freeze and preferably should have a breakable bottom. Its location should also be chosen with a view to making it accessible for reading and removing for testing.

TABLE 9.—RATES OF USE OF WATER BY PLUMBING FIXTURES
(Adapted from C. M. Saville, Hartford, Conn.)

Fixtures	Rate of use (gal. per min.)
1. Flushometer closets.	
Operating singly	33.75
Three operating in quick succession	75.0
2. Shower baths.	
10 continuously	45.0
5 continuously	30.0
10 continuously and four flushometer closets operated in quick succession	90.0
3. Urinals.	
22 operated in quick succession by two persons	37.5
4. Hydraulic lift	135.0
5. Hydraulic lift	150.0
6. 6-inch plunger hydraulic elevator	225.0
7. Washing machine.	
Filling 2—150 shirt machines	225.0
Filling 1 large machine	127.5
8. Filter at National Bank	90.0
9. Filter at school, limit of capacity	172.5
Washing filters	75.0

TABLE 10.—SUMMARY OF DATA ON TEN MAKES OF DISK METERS
(Adapted from Saville, Hartford, Conn.)

Size (inches)	Price	Weight (pounds)	Length (inches)	Height (inches)	Diameter (inches)	Approx. delivery in gallons per minute with stated loss of pressure			
						5 lb.	10 lb.	15 lb.	20 lb.
⅝	$ 7 75	10	7⅝	7⅜	6 3/16	8.4	11.8	14.5	16.0
¾	10 20	13½	9	8	8	12.6	17.8	21.8	25 0
1	13 75	20	10½	8½	9¾	25 2	35 5	43.6	50 0
1½	27 00	38	14½	12⅝	12¼	42.0	59 0	73 0	85 0
2	45.60	58	16½	12½	14¼	63.0	89.0	109.0	130 0

Guaranteed accuracy—Maximum rate, 98 to 99 %; medium rate, 98 %; minimum rate, 90 to 95 %.

TABLE 11.—SIZE OF METER REQUIRED

1 to 6 families	⅝-in meter
6 to 12 families	¾-in. meter
12 to 18 families	1-in. meter
18 to 25 families	1½-in. meter

TABLE 12.—MAXIMUM PROPER RATE OF FLOW AND LOST HEAD THROUGH DISC METERS, TOGETHER WITH THE LENGTH OF STRAIGHT PIPE WHICH GIVES THE SAME LOST HEAD AT THIS RATE
(Adapted from C. M. Saville, Hartford, Conn., Tests on Meters)

Size of meter (inches)	Maximum rate of flow (gal. per min.)	Approximate lengths in feet of straight pipe to give same loss — Diameter of pipe (inches)							
		¾	1	1½	2	3	4	6	8
⅝	16	50	165						
¾	25	20	70	600					
1	50	..	20	160	450				
1½	85	..	...	60	170	1250			
2	130	..	...	30	80	570	2300		
3	335	..	...	...	15	100	400	2900	
4	525	..	...	...	...	45	175	1200	
6	900	...	...	. .	...	....	65	400	1900

USEFUL HYDRAULIC DATA

31. Pressure of Water.—Pressure of water is usually expressed in pounds per square inch p and head or depth of water in feet h.

$$p = 0.434h \qquad \text{(lb. per sq. in.)}$$
$$h = 2.304p \qquad \text{(head in feet)}$$

This relationship holds for a static condition whether the pressure or head is created by gravity as from a tank, or by direct pressure from a pump or ram. These same quantities expressed in pounds per square foot are

$$P = 62.5\,H \qquad \text{(lb. per sq. ft.)}$$
$$H = 0.016P \qquad \text{(head in feet)}$$

The coefficient of P and H will vary slightly with the temperature, being greater for temperatures near 39.1 deg. F. and less for those near the boiling point. For all practical computations it is not necessary to take the variation into consideration.

Where water is flowing in a pipe line from one source, as from a tank at elevation h above point under consideration, the pressure at the end of the pipe is expressed as follows:

$$p = 0.434h - (h_v + h_f + h_i + h_l) \qquad \text{(lb. per sq. in.)}$$

in which h_v = head required to produce velocity of the water, h_f = head to overcome friction in the pipe, h_i = head lost at entrance, and h_l = head available at the end of the pipe, but at the same elevation as point at which p is measured.

32. Flow of Water in Pipes.—Many scientists have derived formulas for the flow of water in pipes, from experiments and theoretical considerations.

TABLE 13.—PRESSURE REQUIRED TO RAISE WATER TO TOP STORY OF BUILDINGS WITH TOP OF TANK 40 FT. ABOVE ROOF, UNDER OPERATING CONDITIONS; ALSO SIZES OF PIPE USED UNDER THESE CONDITIONS
(Hazen & Williams' tables used for loss of head)

Pressure required (lb. per sq. in.)	Number of stories	Elevation in feet		Size of pipe* to supply all floors	Number of people supplied	Gallons per	
		Building	Top of tank			Hr.	Min.
34	1	17	57	1	100	420	7
39	2	30	70	1¼	200	840	14
43	3	43	83	1½	300	1200	20
53	4	50	90	1½	400	1500	25
54	5	63	103	2	500	1980	33
65	6	75	115	2	600	2400	40
63	7	88	128	2½	700	2700	45
70	8	100	140	2½	800	3120	52
78	9	113	153	2½	900	3600	60
78	10	125	165	3	1000	3900	65
86	11	138	178	3	1100	4200	70
93	12	150	190	3	1200	4500	75

Notes on Table 13.—Only one riser pipe is assumed to supply building and the elevation chosen is sufficient to give 25 lb. on highest floor from municipal, elevated, or pneumatic tank supply. Friction loss based on maximum rate, assumed at twice the average for 24 hr. 20 % of friction loss in pipe and velocity head is added to cover loss in elbows and faucets. Where number of people are less or consumption per capita is less, the smaller sizes of pipe can be extended to higher stories.

* Supply assumed to come from public supply or private in basement or at ground level; velocity for average supply 3 to 4 ft. per second.

If supply is to come from elevated tank on roof, then the largest size of pipe should extend from basement to roof. Example.—(*a*) What size of pipe should be chosen for an 11-story building supplying 1100 people with tank on roof? (*b*) With municipal supply?

(*a*) 3 in. for full 11 stories. (*b*) 3 in. for first 2 stories, 2½ in. for next 3 stories, 2 in. for next 2 stories, 1½ in. for next 2 stories, 1¼ in. for the next, and 1 in. for the last story.

Example.—What size of pipe should be used for a 6-story building supplying 1200 people with 4500 gallons of water?

In this case the size should be chosen for the supply and not the floor, so a 3-in. should be used. The pressure required would be slightly less than 65 lb.

One of the simplest and most commonly used is the Darcy formula in which

$$h = f \cdot \frac{lv^2}{d \cdot 2g} \qquad \text{(head lost in feet)}$$

in which h = loss of head in feet.
f = a coefficient approximately = 0.02.
l = length of pipe in feet.
d = diameter of pipe in feet.

v = velocity in feet per second.
g = gravity.
Q = cubic feet per second.

Tables have been prepared by Weston, Williams and Hazen, and others, showing the loss of head for all standard sizes of pipes and covering a wide range in discharge.

From the above formula the following relationship may be found:
The loss of head (h) varies directly with the square of the discharge (Q).
The loss of head (h) varies inversely with the fifth power of the diameter (d).
The discharge (Q) varies directly with the five halves power of the diameter.
The discharge varies inversely as the square root of the length (l) and directly as the square root of the loss of head (h).

33. Head Lost in Elbows, Tees, Valves, Etc.—Besides the head lost in friction in straight pipe due to the flow of water, there are other losses, such as occur in elbows, tees, valves, and meters. The condition of the surface of the interior of the elbow or tee, its diameter, and radius, effect the loss of head to such an extent that no very definite rule can be made as to the amount of this form of loss of head in a pipe system. The loss may be expressed in several ways, but for convenience it is best to express it in equivalent length of pipe of same size. The following extract is from the *Engineering News*, issue of June 10, 1917, p. 38:

The loss of head in long turn elbows 2½ to 8 in. in diameter for all flows is about equal to that in 4 ft. of pipe of same diameter; for same sizes with short radius, the loss of head is equal to that in 9 ft. of pipe of same diameter. For tees with long radius, the equivalent is 9 ft. and with short radius 17 ft. Loss of head in ⅛-in. bends is about equal to 5 ft. of pipe.

TABLE 14.—LOSS OF HEAD THROUGH PIPE ELBOWS
(Bulletin 1759, University of Texas)

Diameter of bend in inches	½	¾	1	1½	2	2½	3	3½	4
Equivalent length of straight pipe in feet. Velocity 1 ft. per sec.	1.2	1.7	2.2	3.25	4.3	5.35	6.4	7.45	8.5
2 ft. per second	1.3	1.9	2.5	3.75	4.9	6.1	7.3	8.5	9.7
3 ft. per second	1.5	2.1	2.75	4.0	5.3	6.6	7.9	9.2	10.5

In Tables 15 and 16 are given all of the available data on the loss of head in wide open valves. For data on the loss of head in valves partly open, see Bull. 105, Engr. Exp. Station, University of Illinois.

TABLE 15.—LOSS OF HEAD IN GATE VALVES
(Compiled by Charles I. Corp from experiments in the hydraulic laboratory of the University of Wisconsin)

Valves wide open

Size of valve in inches	½	¾	1	1½	2	3	4	5	6
Equivalent length of straight pipe in feet	1.5	1.75	2	2.5	3	3.5	4	4.5	5

Table 16.—Loss of Head in Globe, Angle, and Check Valves
(Compiled by Charles I. Corp from various sources, representing practically all published data obtainable)

Type of valve	Globe			Angle			Check			
							4 in.		6 in.	
	1 in.	1½ in.	2 in.	1 in.	2 in.	1½ in.	A	B	A	B
Equivalent length of straight pipe in feet. . . .	15	25	30	10	11	30	25	130	50	200

"A" Pratt and Cady Check Valve.
"B" Walworth Globe Check Valve.

34. Ratio of Capacities of Pipes.—It is often desirable to know how many pipes of a given size are equal to one pipe of a larger size. Pipe sizes are to each other as the squares of their diameters and this relation is often erroneously used for the ratio of capacities. Table 17 gives the correct relationship based on carrying capacity, as nearly as can be stated for all rates of flow.

Table 17.—Ratio of Pipe Capacities
(Diameter of Pipe in Inches)

Dia.	⅜	½	⅝	¾	1	1¼	1½	2	2½	3	4	5	6	8	10
⅜	1.0	0.555	0.357	0.267	0.14	0.067	0.045	0.025							
½	1.8	1.0	0.557	0.50	0.25	0.125	0.084	0.046	0.025						
⅝	2.8	1.8	1.0	0.56	0.30	0.17	0.103	0.019	0.027	0.0167					
¾	3.8	2.0	1.6	1.0	0.53	0.25	0.20	0.10	0.054	0.033	0.0154				
1	7.0	4.0	3.4	1.9	1.0	0.50	0.32	0.18	0.10	0.0625	0.029	0.0161			
1¼	15.0	8.0	6.0	4.0	2.0	1.0	0.66	0.38	0.21	0.13	0.06	0.033	0.0209		
1½	22.5	12.0	10.0	5.0	3.1	1.5	1.0	0.57	0.31	0.19	0.09	0.0509	0.0314		
2	40.0	21.7	20.5	10.0	5.4	2.7	1.8	1.0	0.56	0.34	0.16	0.09	0.056		
2½	.	40.0	37.5	18.7	10.0	4.8	3.2	1.8	1.0	0.63	0.29	0.16	0.101		
3	..	....	60.0	30.0	16.0	7.8	5.2	2.9	1.6	1.0	0.47	0.26	0.16	0.077	
4		...	...	65.0	31.0	16.7	11.0	6.3	3.4	2.1	1.0	0.56	0.34	0.104	0.09
5	..	. .	....	. .	61.0	30.0	19.65	11.3	6.1	3.9	1.8	1.0	0.62	0.29	0.16
6	.	. ..	. .	.	.....	47.8	31.8	17.9	9.9	6.2	2.94	1.6	1.0	0.47	0.25
8	...	.	. ..	.	. .	...	....	....	. .	13.2	6.13	3.4	2.1	1.0	0.55
10	....	..	. .	.	...	....	....	....	..	20.3	9.9	6.3	4.0	1.8	1.0

Illustrative Problem.—What diameter pipe should be used to supply six 1-in., four ¾-in., and eight ½-in pipes?

Reduce all sizes to equivalent 1-in. pipes from Table 14 as follows:

6—1 in. = 6—1-in. pipes
4—¾ in. = 2—1-in. pipes
8—½ in. = 2—1-in. pipes
All = 10—1-in. pipes
1—2½ in. = 10—1-in. pipes

That is, ten 1-in. pipes are equivalent to one 2½-in. pipe. Where the total number of equivalent pipes does not exactly equal one large pipe, *i.e.*, suppose the above total had been 13 instead of ten 1-in. pipes, we should use a 3-in. pipe as it is the next larger size that could be used. It is not necessary always to use 1 in. for a common base: If 1¼-in. pipe had been used, we should have 5—1¼-in. pipes; 4.8—1¼-in. pipes = 1—2½-in. pipe, giving the same result.

35. Fire Streams.—In Table 18 are given data upon such fire streams as should be used from standpipe service within a building. These streams are intended only for first-aid stream in non-fireproof buildings or for small fires in fireproof buildings. For all non-fireproof buildings, equipment should be provided to supply fire streams outside of buildings and from hydrants on city or private mains. Data for such streams are given in Table 19.

TABLE 18.—FIRE STREAM DATA FOR STANDPIPE SERVICE

Elevation above hose connection in feet	¼-in. nozzle, 100 ft. of 1-in. hose			⅜-in. nozzle, 100 ft. of 1½-in. hose			⅝-in. nozzle, 100 ft. of 2-in. hose			¾-in. nozzle, 100 ft. of 2-in. hose		
	Height of jet	Gallons per minute	Loss of head in hose	Height of jet	Gallons per minute	Loss of head in hose	Height of jet	Gallons per minute	Loss of head in hose	Height of jet	Gallons per minute	Loss of head in hose
10	9.37	3.6	2.0	9.7	14.5	3.0	9.7	22.7	2.2	9.8	32.8	4.5
20	17.5	5.1	3.0	18.7	20.6	5.5	19.0	32.2	4.4	19.2	46.2	9.0
30	24.4	6.4	5.0	27.2	25.2	7.5	27.7	39.4	6.6	28.3	56.8	12.8
40	30.0	7.3	7.0	35.0	29.6	11.0	36.0	45.5	8.3	37.0	65.5	16.5
50	34.0	8.1	7.8	42.2	32.5	12.8	44.0	50.9	10.0	45.0	73.3	19.6
60	37.5	8.9	9.7	48.7	35.6	15.0	51.0	55.7	12.0	52.0	80.3	23.8
70	39.0	9.6	11.0	55.0	38.5	17.0	58.0	60.1	13.9	60.0	86.8	25.0
80	39.4	10.3	12.0	60.0	41.2	19.5	64.0	64.3	16.0	67.0	92.6	31.0
90	40.0	10.9	14.0	65.0	43.7	20.0	70.0	68.3	17.0	73.0	98.4	34.2
100	40.5	11.6	16.4	69.0	46.1	24.0	75.0	72.0	19.6	79.0	103.7	38.0

TABLE 19.—FIRE STREAM DATA FOR HYDRANT SERVICE

Pressure in pounds at nozzle	¾-in. nozzle, 100 ft. of 2½-in. hose			1-in. nozzle, 100 ft. of 2½-in. hose			1⅛-in. nozzle, 100 ft. of 2½-in. hose		
	Height of jet	Gallons per minute	Loss of head in hose	Height of jet	Gallons per minute	Loss of head in hose	Height of jet	Gallons per minute	Loss of head in hose
10	17	52	1	18	93	2			
20	33	73	2	35	132	5	36	168	8
30	48	90	2	51	161	7	52	206	12
40	60	104	3	64	186	10	65	238	16
50	67	116	4	73	208	12	75	266	20
60	72	127	5	79	228	15	83	291	24
70	76	137	5	85	246	17	88	314	28
80	79	147	6	89	263	20	92	336	32
90	81	156	7	92	279	22	96	356	36
100	83	164	8	96	295	25	99	376	40

36. Sprinkler Systems.—The dry pipe system is one in which water is turned into the main pipes that supply the pipes in the building, but an air pressure greater than the water pressure is maintained in the distributing pipes. When a sprinkler is open, the air in the pipe system immediately begins to escape. The air pressure is thus lowered and water automatically flows into the system and escapes through the open sprinklers. The dry system is desirable only in places where wet pipes will freeze. The general Underwriter's requirements for proper installation of sprinkler systems call for the use of two independent water supplies, in order to secure the minimum rate of insurance, which may be from 30 to 50% reduction on the total insurance rates. One of these supplies must be automatic and one should furnish water under heavy pressure. The Underwriters accept the following combination:

Public Water Works and Duplex Steam Pump.
Public Water Works and Air Pressure Tanks.
Elevated Gravity Tank and Duplex Steam Pumps.
Public Water Works and Elevated Gravity Tank.
Public Water Works and Rotary Pumps.
Elevated Gravity Tank and Air Pressure Tank.
Elevated Gravity Tank and Rotary Pumps.

A steam pressure of not less than 50 lb. should be maintained at all times on the pumps, and an automatic regulator should be applied to the steam pump so that it will start automatically when a sprinkler is unsealed, thereby furnishing the system with a full supply of water.

TABLE 20.—LOSS OF HEAD IN $2\frac{1}{2}$-IN. FIRE HOSE
Hydrant pressure 100 lb. (from S. A. Charles)

Length of hose (feet)	Pressure at nozzle (pounds per square inch)	Loss of pressure in hose (pounds per square inch)	Discharge gallons per minute
50	87.0	13.0	274
100	80.0	20.0	262
200	69.2	30.8	243
300	61.2	38.8	231
400	55.7	44.3	218
500	50.0	50.0	208
600	45.5	54.5	198
700	41.5	58.5	189
800	38.1	61.9	180
900	34.8	65.2	173
1000	30.0	70.0	161
1500	22.4	77.6	138

Number of Automatic Sprinkler Nozzles, Underwriter's Rules.—The approximate number of sprinkler nozzles for open joist construction is one to every 80 sq. ft. of floor space; for fireproof construction, one to 90 to 100 sq. ft. of floor space. Nozzles are usually spaced 8 to 12 ft. apart on the pipe line and the lines 10 to 12 ft. apart, depending on the size of the bays made by the joists and floor beams.

SIZE OF PIPES AND NUMBER OF NOZZLES

Size of pipe (inches)	¾	1	1¼	1½	2	2½	3	3½	4	5	6
Maximum number of sprinklers.	1	2	3	5	10	20	36	55	80	140	200

Pressure.—The supply should give not less than 25 lb. static pressure at the highest line of sprinklers and 10 lb. dynamic pressure when the section is liable to be open at one time.

Tanks, Gravity.—Capacity, 30,000 gal., 75 ft. from yard level with bottom at least 20 ft. above highest sprinkler.

Tanks, Pressure.—Total capacity 45,000 gal.

DISCHARGE OF SPRINKLER NOZZLES
(Average of four records)

Pounds, pressure	5	10	20	30	40	50	60	70	80	90	100
Gallons per minute.	12	17.5	25	30.5	35.5	40	44	48	51.5	54.7	58

The Grinnell metal disc sprinkler discharges 10% less, the Walworth 10% more, and the Esty 20% more water than the above. The discharge of these sprinklers is about a mean between open ⅜- and ½-in. straight nozzle.

37. Standpipe and Hose Systems—*Number of Standpipes.*—There shall be one large standpipe for 2½-in. hose to each accessible floor area not exceeding 150 × 75 ft.; for 1¼-in. and 1½-in. first aid hose streams, one to each 80 × 40 ft. of accessible floor area. First aid hose lines must reach within 5 ft. of all portions of the building, and 2½-in. hose streams within 10 ft. of all portions of the building. 2½-in. hose should have 1⅛-in. nozzles; and 1½-in. hose, ½- to ¾-in. nozzles.

Tanks.—Gravity tanks should have a capacity of 2500 gal. with bottom 20 ft. above roof; pressure tanks same as for sprinkler systems.

TABLE 21.—AREA, DIMENSIONS, AND CONTENTS OF WROUGHT-IRON PIPES

Diameter (inches)	Area (square feet)	Internal area (square inches)	External area (square inches)	Internal circumf. (inches)	External circumf. (inches)	Gallons per foot of length
½	0.0021	0.304	0.554	1.957	2.642	0.0158
¾	0.0037	0.533	0.866	2.589	3.299	0.0277
1	0.0059	0.861	1.358	3.292	4.134	0.0447
1½	0.0141	2.036	2.835	5.061	5.970	0.1058
2	0.0233	3.356	4.430	6.494	7.461	0.1743
2½	0.0332	4.780	6.492	7.754	9.032	0.2483
3	0.0513	7.383	9.621	9.636	10.996	0.3835
3½	0.0687	9.887	12.566	11.146	12.566	0.5136
4	0.0884	12.730	15.904	12.648	14.137	0.6613
4½	0.1109	15.961	19.635	14.153	15.708	0.829
5	0.1388	19.986	24.301	15.849	17.475	1.038
6	0.2005	28.890	34.472	19.054	20.813	1.500
7	0.2691	38.738	45.664	22.063	23.954	2.012
8	0.3479	50.027	58.426	25.076	27.096	2.599
9	0.4352	62.730	72.760	28.277	30.333	3.259
10	0.5474	78.823	90.763	31.475	33.772	4.095
12	0.7854	113.098	127.677	37.70	40.05	5.875

SIZES OF STANDPIPES FOR 2½-IN. HOSE AND 1⅛-IN. STREAM

Pipe size	Number of floors	Height of building	Number of streams
4	4	55	4
5	6	75	6
6	12	150	8
8	over 12		

SIZES FOR 1¼-IN. AND 1½-IN. HOSE FIRST AID STREAMS

2	4	50	2–50 gallon streams.

38. Rain Leaders or Down Spouts.—No very definite rules can be laid down for the runoff from roofs or the size of rain leaders, for the reason that there are so many modifying conditions that cannot be previously judged or estimated. The entrance to the down spout or leader may be well designed but at the time of an unusual storm would be clogged with leaves and other debris. However, if we assume favorable conditions to exist, and that the head of water maintained by the rain over the inlet to the down spout is used to overcome the resistance at the inlet and to produce the velocity in the leader at its starting point, then the relationships between intensity of rain, areas of roofs, and sizes of down spouts are given in Table 22.

This table is prepared on the assumption that the flooding of the inlet of rain leader is ½ in., ¾ in., and 1 in. for small (*S*), medium (*M*), and large (*L*) roofs, respectively. Intensity of rainfall for a few minutes, as 15, may reach 3.5 in. in Eastern and Central United States. These values for intensity of 2 in. per hour agree well with the

following approximate rule: For small roofs, 1 sq. in. in sectional area of the leader for each 150 sq. ft. of roof surface; for medium sized roofs, 1 sq. in. in sectional area of the leader for each 200 sq. ft. of roof surface; and for large roofs, 1 sq. in. in sectional area of the leader for each 250 sq. ft. of roof surface.

TABLE 22.—SIZE OF RAIN LEADERS FOR INTENSITIES OF RAIN AND AREAS OF ROOF IN SQUARE FEET

		Intensity of rain in inches per hour								
Relative size of roof	Size of rain leader (diameter in inches)	1 in.	1½ in.	2 in.	2½ in.	3 in.	3½ in.	4 in.	5 in.	6 in.
S	2½	1728	1150	864	692	576	494	432	345	288
M	2½	1918	1278	951	766	639	548	479	384	319
L	2½	2107	1605	1205	962	802	688	620	482	401
S	3	2407	1605	1205	962	802	688	620	482	401
M	3	2885	1925	1444	1155	962	824	722	577	481
L	3	3370	2248	1685	1349	1124	963	843	674	562
S	4	3810	2560	1920	1535	1282	1098	960	768	640
M	4	4800	3200	2100	1922	1600	1374	1200	961	800
L	4	5770	3850	2885	2310	1925	1650	1444	1144	953
S	5	6000	4000	3000	2100	2000	1715	1502	1200	1000
M	5	8115	5405	4057	3245	2705	2320	2030	1624	1355
L	5	9620	6420	4810	3850	3210	2750	2405	1925	1605
S	6	9620	6420	4810	3850	3210	2750	2405	1925	1605
M	6	12000	8000	6000	4800	4000	3460	3000	2400	2000
L	6	14400	9600	7200	5760	4800	4115	3600	2880	2400

Rainfall which might effect the size of rain leaders or the size of cisterns for roof water are best expressed in formulas:

i = intensity of rain in inches per hour.
t = time in minutes from the beginning of the storm.

British storms

Very rare $i = \frac{240}{t + 30}$

Unusual $i = \frac{168}{t + 30}$

Numerous storms $i = \frac{84}{t + 30}$

Central Europe

Once a year $i = \frac{36}{t + 10}$

Talbot's curves for U.S.A.

Eastern states, maximum $i = \frac{360}{t + 30}$

Ordinary storms $i = \frac{105}{t + 15}$

These formulas are typical of the temperate zone. The numerator of all of these formulas is usually 25 times the maximum 1-day rain in 20 yr.

PUMPING EQUIPMENT

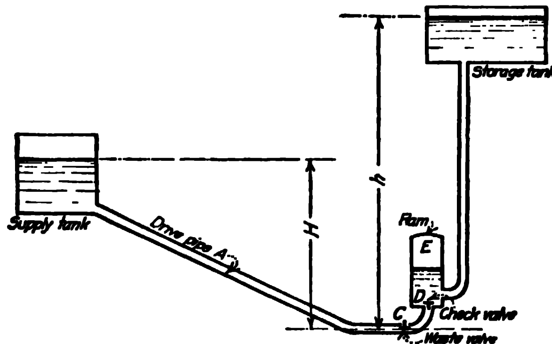
39. Hydraulic Rams.—The hydraulic ram is the most efficient pumping engine known, because it is both a motor and a pump. It operates on the principle of a water hammer; that is, a quantity of water in a pipe called *drive pipe* is allowed to get up a high velocity by flowing freely into the atmosphere when suddenly a valve is closed. The energy of the moving water is then transformed into pressure, thus driving a portion of it to a higher elevation or against a pressure greater than the static pressure on the drive pipe.

Referring to Fig. 3, suppose that the valve "*C*" is open so that the water entering from the drive pipe "*A*" can flow out freely. The pressure on the under side of "*C*" will gradually increase until the valve is forced to its seat. The energy of the moving water equal to

$$\frac{W}{2g} \qquad \text{(ft. lb. per sec.)}$$

will force the check valve "*D*" open and thus force some of the water into the air chamber "*E*." The recoil or "kicks" backwards will close "*D*" and open "*C*," thus completing a cycle. When the length and size of the drive pipe, and adjustment of the valves "*C*" and "*D*" are proper for the given conditions, the machine will work on indefinitely without any attention. The only cost of operation is the possible replacement of these valves once a year.

Conditions favorable for the installation of a ram are: a supply of water from a spring, stream, or artesian well, greater than 3 gal. per minute; a fall or difference of elevation of 3 ft.



or more; an outlet for the waste water; space for a drive pipe of proper length; and the ratio of fall of water to lift of discharge not over 1 to 8 or 9 for small power heads and not over 1 to 30 for high heads.

The amount (q) of water raised in gallons per minute is given by the following formula:

$$= E\frac{QH}{h} \qquad \text{(gal. per min.)}$$

in which Q = gallons per minute available from source of supply.
q = gallons per minute raised to elevation h.
H = fall in feet from source of supply to ram.
h = elevation in feet above ram to which water is raised.
E = efficiency of ram (about 66⅔ %).

Rams are made single and double acting; single acting raise a part of the water that is used for power, but double acting can use, for instance, a muddy water of a stream for power, and a clear water from an artesian well or spring for the delivered water.

To determine the proper size of ram to use, measure the supply (Q) of water available for power purposes in gallons per minute. Measure the head (H) available for power, which is the distance in feet from the surface of the water in supply to level of waste valve at ram site. The discharge head (h) should also be measured as accurately as possible by level or surveying instrument. To this head should be added the friction head and velocity head, where the quantities of water are large. The size of the drive pipe for small rams should be such that the average velocity of the power water will be about 1.5 ft. per sec.

There are many makes of the smaller rams that can be secured from any large jobbing house. There are two companies at least that make large rams; these are the Rife Hydraulic Mfg. Co., and the Niagara Hydraulic Engine Co.

To use Table 23, select number of ram corresponding to the flow of the stream or well, provide drive and discharge pipes of diameter given opposite this number.

The length of the drive pipe for No. 1 to No. 4 incl. should be 60 ft. or more; for sizes No. 6 to No. 48 the length will depend upon the ratio of power head to discharge head and should be estimated for each installation.

Table 23.—Trade Information on Capacities of Niagara Rams

No. of ram	Diameter of drive pipe (inches)	Flow of spring, stream, or artesian well (gallons per minute)	Fall of power water in feet		Diameter of discharge pipe (inches)	Will elevate for each foot of fall	Limit of discharge, elevation in feet	Weight	Price	
			Min.	Max.					Single	Double
00	½	½ to 2	3	40	⅜	30	300	35	$ 20	$....
0	¾	2 to 4	3	40	½	35	400	50	28	....
1	1	5 to 11	3	40	¾	35	400	190	45	60
1½	1½	8 to 18	3	40	1	35	400	292	55	70
2	2	10 to 25	2	40	1	35	400	400	60	80
3	3	20 to 40	2	40	1½	35	400	500	75	90
4	4	35 to 75	1½	40	2	30	300	779	145	465
6	6	100 to 200	1½	30	3	35	300	1,600	400	926
12	12	400 to 900	1½	50	6	35	800	6,000	1200	1350
18	18	1,000 to 1,800	1½	50	9	35	800	9,000	1800	1950
24	24	1,600 to 3,600	1½	50	12	35	800	12,000	2660	2775
36	36	3,500 to 9,000	1½	40	18	35	500	14,050	3480	3685
48	48	9,000 to 15,000	1½	40	24	35	500	16,000	4350	4475

40. Deep Well Plunger Pumps.—Deep well plunger pumps are generally used where a relatively small quantity of water is desired, or where the size and depth of the well will not permit the use of other types of pumps. They are usually single acting, raise water on up

Table 24.—General Data Paul Type "H" Deep-well Pumps

Catalogue number	Stroke, inches	Up strokes per minute	Horsepower	Well cylinder		Capacity, gallons per hour	Size drop pipe, inches	Small estimate well casing, inches	Pump rod		Discharge pipe, inches	Maximum total head, feet	Depth to water at 50 lb. discharge
				Artesian	Flush capacity				Octagon ash	Round steel			
51-*H*	6	44	¾	1¾	...	164	2	3	1⅛	..	¾	340	260
51-*H*	6	44	¾	2¼	...	273	2½	4	1⅝	..	1	210	130
51-*H*	6	44	¾	2¾	...	407	3	4	1⅝	..	1¼	140	60
53-*H*	8	44	1	1¾	...	220	2	3	1⅛	..	¾	360	280
53-*H*	8	44	1	2¼	...	363	2½	4	1⅝	..	1	220	140
53-*H*	8	44	1	2¾	...	513	3	4	1⅝	..	1¼	150	70
54-*H*	10	40	2	2¼	...	413	2½	4	1⅝	..	1	450	370
54-*H*	10	40	2	2¾	...	616	3	4	1⅝	..	1¼	300	220
54-*H*	10	40	2	3¼	...	862	3½	4½	1⅞	..	1½	220	140
54-*H*	10	40	2	3¾	...	1147	4	6	1⅞	..	2	170	90
54-*H*	10	40	2	...	3¼	862	2½	4	...	⅝	1½	190	100
54-*H*	10	40	2	...	3½	1000	2½	4	...	⅝	1½	170	80
56-*H*	12	40	3	...	3	883	2	3½	...	⅝	1¼	310	180
56-*H*	12	40	3	...	3¼	1033	2½	4	..	⅝	1½	260	150
56-*H*	12	40	3	...	3¾	1375	3	4½	...	⅝	2	200	110
56-*H*	12	40	3	...	4¼	1770	3½	5	...	⅝	2	150	90

Note.—"Maximum total head" means the total distance in feet from lowest water level to highest point of discharge. If the pump will discharge into a pneumatic tank, the maximum total head will be the distance in feet from the lowest water level to the pump added to the maximum discharge pressure at the pump converted into feet.

stroke so far as cylinder is concerned, but where lift is above discharge head of pump, some makes have a differential plunger which delivers half of the water raised by the cylinder on the down stroke. Other makes are double acting with two or more lifting rods, or one large one that raises water on the down stroke. Complicated deep well pumps should be avoided where possible.

For heavy duty, the "*A*" frame type of head is best. These pumps may be operated by belt or by gears from motor, or the cylinder rod may be operated by a direct acting steam head, which is very uneconomical in the use of steam and gives very poor service. Table 24 gives a fair notion of the trade sizes of small deep well pumps and what they will do.

41. Rotary or Impeller Pumps.—The rotary pump consists of a series of impellers (helixes) on a shaft placed in the well, extending from a point below the water to the surface of the

TABLE 25.—TRADE DATA ON DEEP-WELL IMPELLER AND TURBINE PUMPS*

Size of well and number of pump	U. S. gallon per minute		Speed, normal r.p.m.	Water horsepower† per 100 ft. of lift for maximum capacity	Turbine pumps, capacities g.p.m.		Maximum lift, feet
	Minimum	Maximum			Minimum	Maximum	
6	100	300	1,750	7½			
8	200	600	1,750	15			
10	450	1,200	1,445	30	75	100	75
12	800	2,000	1,445	50	250	350	125
14	1,200	3,000	1,150	75	400	600	175
16	1,800	4,000	1,150	100	700	1,000	225
18	3,000	6,000	865	150	1,100	1,400	250
20	....	....	....	.....	1,500	2,000	275
24	....	....	....	.....	2,000	2,500	300

* Capacities are approximate only.
† Maximum lift 150 ft.

ground. Rotary pumps are used where the water is delivered at the surface of the ground, as for irrigation, or into a surface reservoir. They are best operated by a vertical shaft motor or a cross belt from other motive power. They are particularly adapted to use where large quantities of water are desired from relatively small and shallow wells where an air lift or turbine pump could not be used. There is at least one very serious objection to their use as well as to other deep well pumps of a rotary type, and that is that all of the moving parts are below ground where it is difficult to get at them for renewal or repair.

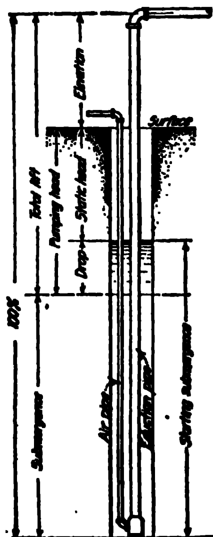


FIG. 4.

42. Air Lift Pumps.—The air lift pump is dependent for its operation on the principle that an emulsion of air and water has less specific gravity than water alone. The column of water outside the pump is balanced against the column of air and water within the pump in the form of an emulsion. To bring these conditions about, the pump, while in operation, must extend into the water a sufficient distance to produce the proper mixture. The water is raised from the well due to the energy stored in the compressed air and by its ability to absorb heat from the water. The idea that the operation of the air lift pump is based on the ejector principle, is erroneous. There are certain terms used in air lift pumping which will be defined here (see Fig. 4).

Static lift—Distance in feet from level of water in well to surface of ground = h_s.

Pumping lift—Distance in feet from level of water, when pumping, to surface of ground = h_p.

Static submergence—Distance from surface of water to air inlet on pump before pumping starts = S_s.

Pumping submergence—Distance from surface of water to air inlet on pump during puming = S_p. Usually expressed as a percentage of the total length of the pump and should vary slightly with the lift.

Drop or *lowering*—Distance water recedes in well due to pumping and caused by friction in the well itself = difference between static lift and pumping lift.

Elevation—Distance water is raised above ground = E.

Total lift—$H = h_p + E = h_s + (S_p - S_s) + E$. (Head in feet)

Air pipe—Pipe leading compressed air from surface of ground to air inlet of pump.

Eduction pipe—The pipe or well casing discharging the emulsion of air and water.

Foot piece.—A casting with orifice, nozzle, or tube in which the air and water are mixed.

Air Pump Design.—There are so many factors entering into the operation of the air lift pump that no hard and fast rules can at this time be laid down for its design, or for its selection for a given set of conditions (see University of Wisconsin Bulletin No. 1265, "Air Lift Pumps," by Ward).

Table 26.—Trade Information on Air Lift Pumps

Size and Capacities of Indiana Air Pumps

Size of pump and discharge (inches)	Minimum size of casing (inches)	Minimum size of air line (inches)	Maximum capacity in gallons per minute 65 to 70% submergence
1	2½	¼	5– 10
1¼	3	⅜	10– 20
1½	3½	½	20– 30
2	4	½	50– 67
2½	4¾	¾	65– 85
3	5⅝	¾	120– 165
3½	6	¾	160– 275
4	6⅝	1	225 - 325
4½	7⅝	1	275 - 400
5	8	1	350 - 600
6	9⅝	1½	550 -1000
7	10⅝	1½	750–1200
8	11⅝	1½	1000–1500
9	13	2	1250–2000
10	14	2	1600–2500

Table 27.—Size and Capacity of Sullivan Air Lifts

Size discharge (inches)	Approximate capacity (gallons per minute)	Diameter well head (inches)	Approximate shipping weight (pounds)
1	5	4	65
1¼	10	4	75
1½	20	4	85
2	50	6	125
2½	75	6	135
3	100– 150	6	150
3½	150– 200	8	175
4	200– 300	8	185
4½	300– 350	8	200
5	350– 500	10	250
6	500– 800	10	300
7	800–1500	12	350

Trade catalogs give the following information as to proper submergence:

Feet	Per cent submergence
For lifts up to 50	70 to 66
50 to 100	66 to 55
100 to 200	55 to 50
200 to 300	50 to 43
300 to 400	43 to 40
400 to 500	40 to 33

Some commercial authorities state that the area of the cross section of the eduction pipe should be 1 sq. in. to each 12 to 15 gal. pumped per min. Other authorities, such as Ivens, state that the inlet velocity of the air and water should not be greater than 10 to 12 ft. per sec. at the foot piece and 20 to 25 ft. at the point of discharge. The size of the air pipe can be determined roughly by fixing the maximum velocity of the compressed air at inlet at 50 lin. ft. per sec. (for capacities of pipes on this basis see Table 28).

The quantity of *free* air (at atmospheric pressure) per minute required per gallon of water pumped, is given approximately by the following formula:

$$V_a = \frac{H}{C \log \frac{S_p + 34}{34}} \qquad \text{(cu. ft. air per gal.)}$$

in which V_a = cu. ft. of air per min. per gal. of water pumped.

H and S_p are as given above.

C = a factor which varies as follows:

Lift, feet	Value of C
10 to 60	245
61 to 200	233
201 to 500	216
501 to 650	185
651 to 750	156

The value of C for ideal conditions (100% efficiency) with no loss of head in friction or velocity is 580, and with this value the above formula is theoretically correct assuming no losses. However, these are partially cared for in the values of C to be applied to a given condition.

It has been found in practice that for ordinary lifts the submergence should be about 60% of the entire length of the pump when the pump is in operation. There is no limit to the lift so long as the well is deep enough to provide the proper submergence, and provided the compressor has sufficient strength and power to produce the compressed air at the required pressure.

The pressure required to operate an air lift pump depends entirely upon the submergence and upon the friction in air pipe, elbows, valves, and foot piece. The low efficiency of many air lift pumps is no doubt caused by large losses in air pipes, small openings in nozzle at foot piece, etc., rather than in the real act of pumping the water.

TABLE 28.—CUBIC FEET OF FREE AIR PER MINUTE THAT WILL FLOW THROUGH PIPES WITH A VELOCITY OF 50 FEET PER SECOND WHEN UNDER A GIVEN PRESSURE

(Pressure in pounds per square inch)

Size of pipe (inches)	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
3/4	18.65	22.4	26.2	30.0	33.8	37.5	41.3	45.0	48.8	52.6	56.4	60.3	63.3	67.8	71.5	75.4	79.0	82.9	86.6
1	29.7	35.7	41.8	47.7	53.8	59.8	65.8	71.8	77.8	84.0	89.9	96.0	100.9	108.1	114.0	120.0	126.0	132.0	138.0
1 1/4	72.3	85.5	100.2	114.4	128.9	143.2	157.6	172.0	186.4	200.6	215.0	229.0	241.0	258.0	272.0	287.0	301.0	315.3	329.9
2	117.4	141.2	165.0	188.5	212.5	236.2	260.0	283.5	307.0	331.5	355.0	379.0	398.0	426.5	450.0	474.0	497.5	521.0	545.0
2 1/2	167.5	201.0	227.8	269.0	303.0	337.0	370.5	404.0	438.0	472.5	506.0	540.0	566.5	608.0	642.0	676.0	709.5	743.0	777.0
3	257.2	309.5	361.5	413.5	465.5	518.0	569.0	621.0	673.0	726.4	778.0	830.0	872.0	935.0	986.0	1040.0	1090.1	1142.0	1195.0

Advantages of air lift:

1. Any number of wells and at any distance apart may be pumped by one power plant.
2. More water can be secured from the same wells than by any other system.
3. Sand no obstacle, except as it may erode the pipe or decrease the efficiency.
4. Improvement in the character of the water, due to aeration, as to purity and solubility.
5. All machinery and moving parts are above ground where they can be looked after. No oiling, no break-downs.
6. Reduction in temperature, due to absorption of the heat in the water by the air.
7. Sustained efficiency.

Limitations of system:

Quantity of water.
Submergence.
Vertical not horizontal discharge.

There are three principal systems in use, defined according to the arrangement of piping: the outside air pipe, the central air pipe, and the central discharge pipe system.

Illustrative Problem.—A well 500 ft. deep, and 8 in. in diameter, will supply 250 gal. per min. when the pumping head is 65 ft. and the drop 15 ft. It is desired to raise the water 10 ft. above the surface. Here H_p = 75 ft., S should be 65 % or 112.5 ft., and total length of pump, 187 5 ft. The starting pressure will be 112.5 × 0.434 = 48 8 lb.

From the above equation for V_a with C = 233, we have required 0.51 cu. ft. of air per gal. or a total amount required of 250 × 0.51 127.5, say 130 cu. ft. per min. The volume of this air at 50 lb. pressure is $\frac{(130)(14.7)}{50 + 14.7}$ = 29.5 cu. ft. per min. = 0.492 cu. ft. per sec.

Velocity of air in 1½-in air pipe = $\frac{0.492}{0.0123}$ = 40 ft. per sec., which is a reasonable velocity..

To find the size of the eduction pipe, add 29.5 cu. ft. of air to 38.5 cu. ft. (250 gal.) of water = 68 cu. ft. per min. = 1.333 cu. ft. per sec. At a velocity of 10 ft. per sec., the area of pipe will equal $\frac{1.333}{10}$ = 0.1333 sq. ft. = about a 5-in. pipe.

43. Power Pumps.—There are many types and styles of power pumps on the market, but the most satisfactory and efficient type for suction lifts is the single acting triplex pump. These pumps are made in almost all diameters and strokes from 1 to 12 in.

Table 29 is not trade data, but is compiled for the sizes given based on the theoretical displacement of the plungers. In actual practice there would be a slippage of 5 to 8 % which would reduce the discharge by this amount. The efficiency of well designed standard makes is not far from 75 %.

TABLE 29.—SIZES AND CAPACITIES OF SINGLE-ACTING TRIPLEX POWER PUMPS (SIZES BELOW 7 × 10 AT 60 R.P.M.; ABOVE THIS 45 R.P.M.; GALLONS PER HOUR IN BODY OF TABLE)

Length of Stroke

Diameter	3	4	4½	5	6	8	10	12
1	110	147						
1½	248	331	372	414				
2	441	588	661	735				
2½		917	1031	1146	1225			
3		1322	1490	1653	1984			
3½		1800	2025	2250	2700			
4		2352	2648	2940	3528	4704	5,880	5,286
4½			3347	3765	4601	5950	7,440	6,700
5				4590	5508	7344	9,180	8,262
6					7920	10,560	13,200	11,899
7						14,360	13,500	16,191
8						18,750	17,620	21,180
9							22,500	26,780
10							27,580	33,080
11								39,920
12								47,620

44. Residential Pumping Plants.—The type of plant to select for residences will depend largely upon the source of water supply, and if from a well, whether a suction or deep-well pump will be required. Where electric current is available, pumps are usually operated by motor. A number of manufacturers are not making standard equipments consisting of pump, motor, automatic controller, and storage tanks. These plants can be controlled at any desired pressure between limits of 15 to 20 lb. apart. Where current is not available, gasoline engines, wind mills, or hand pumps may be used. A typical pumping plant is shown in Fig. 5. Tables 30 and 31 give trade data on typical residential pumping plants.

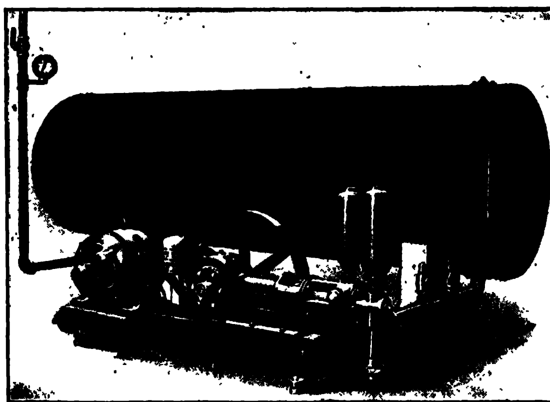


Fig. 5.

Table 30.—Trade Data of the Paul Type "G" Motor Driven Pump

No. of pump	Hp. of	Capacity (gallons per hour)	Maximum working pressure pounds)	Size of pipes (inches)		Space occupied (inches)			Approx. shipping weight of pump and motor (pounds)
				Suction	Discharge	Length	Width	Height	
97-K	1/6	100	50	1/2	1/2	27	9 1/2	23 1/2	100
82-G.M.	1/2	360	50	1	3/4	46	15	26 3/4	325
83-G M.	1	720	50	1 1/4	1	51 3/4	19 3/4	30 3/4	465
84-G.M.	5	1440	50	2	1 1/2	61 3/4	22 3/4	34 3/4	725

Table 31.—Trade Data on Pumping Unit, Suction Type, Kewanee Private Utilities Co.

Number	Piston		Revolutions per minute	Gallons per minute	Gallons per hour	Maximum pressure (pounds)	Hp. of motor	Suction and discharge openings (inches)	Floor space (inch × inch)	Height (inches)	Rev. of motor	Shipping weight (pounds)
	Diameter (inches)	Stroke (inches)										
8-A	2	4	50	5.4	324	75-150	1/2	1 1/4-1	20×30	39	1750	400
35-A	2 1/2	4 1/2	54	10.4	625	90	1	1 1/2-1 1/4	24×45	45	1750	700
35-D	3 1/4	4 1/2	54	16.6	1000	90	2	1 1/2-1 1/4	24×45	45	1750	700

45. Centrifugal or Turbine Pumps.—Centrifugal pumps are made in all sizes, and for pressures within reasonable limits. They are also made with impellers to give almost any characteristics of discharge and head relationship that might be desired, and are built in one or more stages according to the head, speed, and ideas of the designer. They are most efficiently operated by electric motor directly connected to the shaft of the pump. The efficiency of these pumps varies from 45% for small quantities of discharge to 80% for large quantities of discharge against high heads.

Some of the advantages of centrifugal pumps are: low first cost, no loss of energy in transmission of power from motor to pump, quiet running, handles muddy or gritty water with less wear than displacement pumps, needs little attention, and occupies less space than other types of pumps.

Some of the disadvantages are: all air must be expelled from the pump when starting, to insure that it will pump water; the efficiency for small sizes is less than that of plunger pumps; and they are possibly shorter lived than plunger pumps.

TABLE 32.—TRADE DATA ON HORIZONTAL CENTRIFUGAL PUMPS*

Size of pump, inches	Capacity, U. S. grams per minute		Total head, feet	Speed, r.p.m.	Approx. horsepower
	Minimum	Maximum			
2 × 1½	30	150	220 10	1,765- 3,500	¾-15
2½ × 2	100	175	500-35	1,765-3,500	3 -40
3 × 2½	100	300	500-25	1,750 3,500	3 -50
4 × 3	150	450	500-15	1,140-1,750	1½-100
6 × 4	350	650	500-220	1,765-1,765	60 -100
6 × 6	600	1400	300-10	850-1,750	3 -100
8 × 6	900	1800	500-10	850 1,760	5 -300
8 × 8	1100	2250	200-15	850 1,750	7½-200

* Adapated from Allis-Chalmers data book.

46. Fire Pumps.—Fire pumps may be steam, rotary, centrifugal, or power pumps, and of capacities of 500, 750, 1000, and 1500 gal. per min. supplying 2, 3, 4, and 6 fire streams of 250 gal. each and capable of giving a pressure of 100 lb. per sq. in. Size of pump should be chosen to suit the conditions, but before doing so, the local authority of the Underwriter's should be consulted.

47. Fire Engines.—Standard fire engines have the same capacities as Underwriter's pumps, *i.e.*, 500, 750, 1000, and 1500 gal. per min.

48. City Water Lifts.—Where city water is available for power and it is desired to pump some other liquid, as cistern water, a "city water lift" or "water motor" may be inserted in the

TABLE 33.—CITY WATER LIFTS
Cistern water lift in feet

City pressure (lb. per sq. in.)	60	65	70	75	80	85	90	95	100	Factor
15	118	109								7,081
20	131	121	112.5							7,863
25		181	168	157	147	138.5	131	124	117	11,773
30			202	188	176.5	166	157	148.5	141	14,110
35			235	220	206	194	183	173.5	164.7	16,465
40			269	252	236	222	201	198.5	188.7	18,870
45				295	277	261	246	233	212.2	21,216
50				313	294	276	261	247	234.6	23,460
55					324	305	288.5	273	259.25	25,925
60						333	314	298	283	28,305

main supply line to the fixtures. Whenever any water is drawn by a fixture, a corresponding amount of cistern water is raised by the pump. These pumps are made in several sizes, but for illustration, one was chosen that would use 240 gal. per hr. of city water. In Table 33 are given the number of gallons of cistern water raised per hour to elevations given at the top of the table by 240 gal. per hr. under the pressures given in the right-hand column.

To find the number of gallons raised to any other height, divide factor at right-hand by the desired height. Pump efficiency = 85%.

Illustrative Problem.—How many gallons of cistern water will be raised to elevation of 80 ft. by 240 gal. of city water under 50 lb. pressure?

Under column "80 feet," Table 33, and opposite "50 lb.," read "294 gal. per hr."

49. Horsepower Required to Raise Water.—The actual power required to raise water by any pump depends very largely upon the efficiency of the particular type and make of pump under consideration. Most triplex power pumps and some makes of centrifugal (turbines pumps give an efficiency of 75 to 80%. Single acting deep well pumps and impeller pump) give an efficiency of 35 to 60%. A well designed air lift pump should give an efficiency of 30 to 45%.

The theoretical horsepower required to raise water (assuming no losses in the pump) is most easily computed by the following formula:

$$\text{hp.} \frac{QL}{4000} \qquad \text{(Horsepower)}$$

in which Q equals gal. per min. and L equals lift in feet.

The actual horsepower required may be found by dividing the theoretical horsepower by the percentage of efficiency. Where power pumps are driven from a line shaft by belt or gears, an allowance of 5 to 10 % additional power should be allowed for loss of transmission.

50. Windmills.—From Table 34 it will be seen that the only available winds are those blowing with a velocity of from 8 to 25 mi. per hr., and that a 15-mile wind can be utilized to best advantage. It is, therefore, best to "load" a windmill for a 15-mile wind. It then starts pumping in an 8-mile wind, does excellent work in a 15-mile wind, and reaches the maximum results in a 25-mile wind.

TABLE 34.—VELOCITY AND ACTION OF WINDS

Velocity per hour (miles)	Pressure per square foot (pounds)	Description of wind	Action of wind and windmills
3	0.045	Just perceptible	Windmill will not run.
5	0 125	Pleasant wind	Might start if lightly loaded.
8	0.33	Fresh breese	Will start pumping.
10	0.5	Average wind	Pumps nicely if properly loaded.
15	1.125	Good working	Does excellent work.
20	2.0	Strong wind	Gives best service.
25	3.125	Very strong wind	Maximum results secured.
30	4.5	Gale	Should be furled out of wind.
40	8.0	Storm	Well constructed mills and towers safe if properly erected.
50	12.5	Severe storm	Well constructed mills and towers safe if properly erected.
60	18.0	Violent storm	Buildings, trees etc., might be injured.
80	32.0	Hurricane	Buildings, trees, etc., would be injured.
100	50.0	Tornado	Ruin.

TABLE 35. TRADE DATA ON WINDMILLS

Diameter of wheel (feet)	Actual useful horsepower	R. p. m.	25-ft. head			50-ft. head			75-ft. head			100-ft. head			125-ft. head			150-ft. head			200-ft head		
			C	*S*	Gallons	*C*	*S*	Gallons	*C*	*S*	Gallons	*C*	*S*	Gallons	*C*	*S*	Gallons	*C*	*S*	Gallons	*C*	*S*	Gallons
8½	0.08	35	3¼	4	300	2¼	4	150															
10	0.12	35	3¾	8	790	3	7	440	2¾	5	270	2¼	5	180	2	5	150	2	4	120	1¾	4	90
12	0.25	30	5¾	8	1620	4	8	792	3¼	8	518	2¾	8	370	2½	8	310	2¼	8	250	2	8	195
14	0.40	28	5	10*D*	2820	4	8*D*	1450	4¼	8	825	3¾	8	650	3½	8	550	3¼	8	480	2¾	8	350
16	0.55	25	6	10*D*	3670	4	10*D*	1620	4¾	10	1255	4½	8	825	4	8	600	3¾	8	570	3¼	8	430
18	0.75	22	8	8*D*	4590	5	11*D*	2580	5¾	11	1600	5¾	8	1200	4¾	8	810	4¼	8	660	3¾	8	500
20	1.00	20	8	12*D*	6264	5	14*D*	2850	4	14*D*	1825	5¾	12	1600	4¾	14	1280	4¼	14	1030	3¾	14	850
22½	1.10	18	8	14*D*	6500	6	12*D*	3200	5	12*D*	2200	5	10*D*	1800	5¾	12	1440	4¾	14	1150	4¼	14	92[illegible]
25	1.25	16	10	12*D*	7800	8	12*D*	3810	6	12*D*	2800	5	14*D*	2000	5¾	15	1610	5¾	12	1300	4¾	14	103[illegible]

C = Inside diameter of cylinder. *S* = Length of stroke in inches.
Gallons = Gallons pumped per hour. *D* = Double acting pump.

Table 35 is not designed to show what windmills can do in extremely favorable cases in high winds, but it shows what windmills actually do under average conditions when properly loaded. It is based on a wind velocity of 15 mi. per hr., and shows the number of strokes per minute made by a properly loaded windmill in such a wind, and the useful horsepower developed as measured by the work performed in pumping and overcoming the friction in pump and pipe. The tendency is to overload windmills, and this should be avoided by all means. A lightly loaded windmill pumps more water in a year than one that is overloaded.

A large capacity cannot be secured by using a large cylinder unless a large windmill is used to operate it. Do not make the mistake of using a cylinder larger in diameter than shown in table.

The amount of water pumped will vary about as the square of the velocity of the wind between reasonable limits.

TABLE 36.—SUCTION LIFT AT DIFFERENT ALTITUDES

Elevation above sea level in feet	Atmospheric pressure in feet of water	Practical limit of suction
0000	33.9	25.43
1000	32.6	24.45
2000	31.4	23 55
3000	30.2	22 68
4000	29 1	21.82
5000	28.0	21 02
6000	27.0	20.26
7000	26.0	19.50
8000	25.0	18.26

STORAGE OF WATER

51. Wooden Tanks.—Wooden tanks cost only about half as much as steel tanks in the smaller sizes, and especially so where no tower is required. Some of the advantages of wooden tanks over steel tanks are:

1. Steel tanks require skilled boiler makers to erect, thus adding materially to the cost when at a distance from the boiler shop.
2. Wooden tanks are more readily protected from freezing.
3. They do not sweat so much in a building as do steel tanks.
4. They will not deteriorate so rapidly as a steel tank if neglected.

Table 37.—Sizes and Capacities of Wooden Tanks for Fire Protection
A. F. Mut. F. I. Co. Inspection Dept.

Approximate net capacity (gallons)	Size (Outside dimensions)		Thickness of lumber after being planed		Hoops		Approximate price with roof
	Average diameter	Length of stave (feet)	Staves (inches)	Bottom (inches)	Number	Size (inches)	
15,000	14 ft. 6 in.	14	2¼	2¼	14	¾	$407.00
20,000	15 ft. 6 in.	16	2¼	2¼	5 11	¾ ⅞	500.00
25,000	17 ft. 6 in.	16	2¾	2¾	4 12	¾ ⅞	572.00
30,000	18 ft. 0 in.	18	2¾	2¾	4 16	¾ ⅞	654.00
40,000	19 ft. 6 in.	20	2¾	2¾	11 13	⅞ 1	822.00
50,000	22 ft. 0 in.	20	2¾	2¾	4 19	⅞ 1	925.00
60,000	24 ft. 0 in.	20	2¾	2¾	4 22	⅞ 1	
75,000	24 ft. 6 in.	24	2¾	2¾	7 24	1 1⅛	

Table 38.—Trade Data of Small Wooden Storage Tanks

Lenght of stave (feet)	Diameter of bottom (feet)	Number of hoops	Capacity (gallons)	Approximate wt. 2-in. pine or 1½-in. cypress	List price 2-in. pine	List price 1½-in. cypress	Approximate wt. 2-in. cypress	List price 2-in. cypress
2	4	2	117	180	$12.50	$14.00	220	$16.00
6	4	5	410	460	27.00	30.50	550	36.50
2	5	2	195	240	16.20	17.50	290	21.00
7	5	6	784	690	39.00	43.50	830	53.00
2	6	2	292	290	20.00	21.50	350	26.00
10	6	8	1710	960	62.50	68.00	1150	86.00
2	7	2	408	360	25.00	27.50	432	32.50
10	7	8	2335	1300	73.50	80.00	1565	102.00
2	8	2	543	450	29.50	32.00	549	39.00
12	8	9	3816	1700	100.00	.....	2040	136.00
2	9	2	696	645	35.00	39.00	774	46.00
12	9	9	4820	2125	114.00	.....	2550	157.00
2	10	2	870	750	41.00	45.00	900	54.50
12	10	9	5700	2465	132.00	.....	2958	180.00
2	12	2	1270	1000	54.00	.....	1200	71.00
14	12	12	10544	3200	182.00	.....	3840	238.00

The life of a wooden tank is from 12 to 30 yr. (usually 15); cypress tanks often last from 20 to 25 yr.

Specifications for Wooden Tanks.—The following are extracts from the Ass'n Fact. Mut. Fire Ins. Co.'s Inspection Department Specifications:

(1) Lumber.—(*a*) White cedar, cypress, white and red pine, Douglas or Washington fir (Oregon pine), British Columbia fir or redwood must be used. Lumber must be free from rot, sap, loose or unsound knots, worm holes and shakes, and must be thoroughly air-dried.

(2) Staves and Bottom.—(*a*) Planks for staves and bottom must be planed on both sides with the outer surface of staves curved to the radius of the tank.

(b) The lumber must be 2½ in. dressed to about 2¼ in. for tanks not exceeding 16 ft. diameter or 16 ft. deep, and 3 in. dressed to about 2¾ in. for larger tanks.

(c) Splices must not be made in staves or bottom planks.

(d) The edges of staves and bottom planks must be machine planed or sawed.

(3) Hoops.—(a) The hoops must be circular in cross section and not less than ¾ in. in diameter. Not more than two sizes of hoops must be used on a tank.

(b) Hoops must be of wrought iron or steel without welds or upset ends. The wrought iron must conform in its chemical and physical properties to specifications A-40 of the American Society for Testing Materials.

(c) Hoops must be cut to proper length and bent in the shop to the radius of the tank. The sections of a hoop must be of equal length and must be securely fastened together for shipment.

(d) The ends of the hoop sections must be connected by malleable iron lugs and their strength must be not less than that of the hoops. The hoops must be so located on the tank that the lugs come in uniform spiral lines.

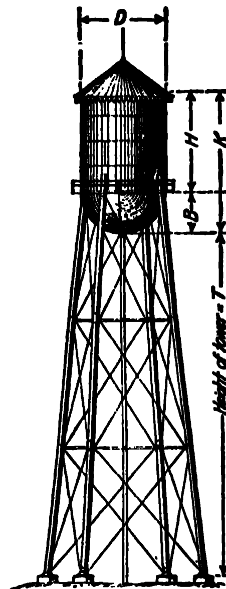


FIG. 6.

52. Steel Tanks and Towers.—The design of steel tanks and towers has become nearly standard with a number of manufacturers who make a specialty of their construction. Any of these firms will build them according to an engineer's specifications at an increased cost. Tanks with either hemispherical or elliptical bottoms can be had.

Elevated steel tanks are almost never built with flat bottoms, supported on I-beams grillage, as is standard or wooden tanks. The specifications given in Table 39 are fairly representative of tank practice. The side of the square enclosing the base of the legs is equal to $0.71D + 0.162\ (T + B)$ (see Fig. 6). The cost of these tanks and towers is about 5 to 6c. per lb. of steel erected.

The riser pipe is enclosed in a frost proof three-ply circular box of wooden staves and layers of building paper.

TABLE 39.—SIZES AND CAPACITIES OF STEEL TANKS

Capacity (thousand gallons)	Hemispherical bottom		
	D	H	K
5	8' 0"	12'-0"	16'-0"
10	10'-0"	14' 0"	19' 0"
15	12' 0"	14' 0"	20'-0"
20	12' 9"	17'-3"	23'-7"
25	14' 1"	17'-3"	24' 3"
30	15' 3"	17'-3"	24'-10"
35	16'-4"	17'-3"	25'-5"
40	17' 4"	17'-3"	25'-11"
45	18' 3"	17'-3"	26'-4"
50	19' 0"	17'-6"	27' 0"
60	19' 0"	22'-3"	31'-9"
65	20' 0"	21'-3"	31' 3"
70	21' 0"	20'-3"	30'-9"
75	22'-0"	19'-4"	30'-4"
80	22'-0"	21'-1"	32'-1"
90	22'-0"	24'-6"	35' 6"
100	22' 0"	28'-0"	39'-0"
120	24'-0"	28'-0"	40'-0"
125	24' 0"	30'-0"	41-0"
150	26' 0"	29'-3"	42'-3"
175	26' 0"	35'-0"	48'-0"
200	28' 0"	35'-0"	49'-0"
250	30'-0"	37' 0"	52'-0"
300	32'-0"	40'-0"	56'-0"
400	35'-0"	44'-0"	61'-6"
500	38'-0"	46'-6"	65'-6"

53. Concrete Tanks and Reservoirs.—Reinforced concrete is cheaper for tanks than sheet steel and more durable than either steel or wood. It is particularly adapted for reservoirs where they are all or partly underground. Concrete is especially adapted in industrial work where the tank is to contain liquors and acid solutions.

Square tanks are most economical of space (as within a building or enclosures), and in some cases in use of lumber for forms, but from the standpoint of greatest capacity for least concrete, the circular type is the most economical. Square or rectangular reservoirs of large size involve high tensile and compressive stresses such as would occur in a retaining wall or dam. The circular type is partially self-sustaining so far as external pressures are concerned and the stresses that do occur are simpler and more easily calculated.

One of the greatest difficulties with concrete tanks is to make them water-tight. A rich mixture with relatively small aggregate and thin enough to flow readily in continuous work makes the best tanks. The interior surface of the walls should be waterproofed also by plastering with cement wash or by some waterproof compound or fabric. For light pressures, ½-in. 1:1 plaster and two coats of cement wash (water and neat cement) will be about as effective as any other method of waterproofing. Except for very small tanks of dimensions less than 15 ft., the side walls should be 10 to 12 in. thick. Where covers are desired or necessary, the flat slab type supported on posts is the most economical and readily constructed.

54. Cisterns.—A cistern for the storage of rainwater, 5 ft. in diameter by 7 ft. deep, capacity 1024 gal., will be large enough for a family of 10 people if located in a climate where the annual rainfall is about 30 in. and well distributed. Larger buildings should have cisterns of about 100 gal. capacity to each person, which, for convenience, may be divided into two or more cisterns.

TABLE 40.—CAPACITIES OF TANKS OR CISTERNS IN GALLONS

Length or depth (feet)	Diameter (inches)									
	18	24	30	36	42	48	54	60	66	72
2	26	47	73	105	144	188	238	294	356	424
2½	33	59	90	131	180	235	298	367	445	530
3	40	71	109	157	216	282	357	440	534	636
3½	47	83	127	183	252	329	416	513	623	742
4	54	95	145	209	288	376	475	586	712	848
4½	61	107	163	235	324	423	534	659	801	954
5	68	119	180	261	360	470	593	732	890	1060
5½	75	131	200	287	396	517	652	805	979	1166
6	82	143	217	313	432	564	711	878	1068	1272
6½	89	155	235	339	468	611	770	951	1157	1378
7	96	167	253	365	504	658	829	1024	1246	1484
7½	103	179	271	391	540	705	888	1097	1335	1590
8	110	191	289	417	576	752	947	1170	1424	1696
8½		203	307	443	612	799	1006	1243	1513	1802
10		239	361	521	720	940	1183	1462	1780	2120
12		287	433	625	864	1128	1419	1754	2136	2544
14					1008	1316	1655	2046	2492	2968
16					1152	1504	1891	2338	2848	3392
18							2127	2630	3204	3816
20							2363	2922	3560	4240

55. Pneumatic Tanks.—Pneumatic tanks are always made of steel or wrought iron as they must be absolutely air tight. Tanks are usually made especially for this purpose, but there is no good reason why any tight tank or boiler could not be used for the purpose if sufficiently strong to stand the pressure.

Table 41.—Trade Data on Pneumatic Tanks

Diameter (inches)	Length (feet)	Thickness			Approx. shipping weight (pounds)	Total capacity (gallons)	Working capacity (gallons)	List price black
		Shell (inches)	Convex head (inches)	Concave head (inches)				
24	5	3/16	1/4	1/4	375	120	80	$ 31.00
24	10	3/16	1/4	1/4	645	235	156⅔	45.00
30	5	3/16	1/4	5/16	500	180	120	37.00
30	12	3/16	1/4	5/16	960	440	293⅓	67.00
36	5	3/16	1/4	3/8	653	265	176⅔	48.00
36	14	3/16	1/4	3/8	1365	740	493⅓	87.00
42	8	1/4	5/16	7/16	1425	575	383⅓	76.00
42	16	1/4	5/16	7/16	2350	1150	766⅔	135.00
48	10	1/4	5/16	7/16	1900	1000	666⅔	124.00
48	24	1/4	5/16	7/16	4000	2260	1506⅔	227.00
60	12	1/4	3/8	3/8	3000	1760	1163⅓	203.00
60	40	1/4	3/8	3/4	8400	5875	3249⅓	517.00
72	12	9/32	7/16	7/16	4140	2535	1690	262.00
72	40	9/32	7/16	7/16	10720	8460	5640	642.00

Formulas and Illustrative Problems for Pneumatic Tanks.—To find the pressure in a pneumatic tank when supplied with initial air pressure and then filled to any portion with water:

$$P_d = \frac{P_a + P_i}{1.00 - F} - P_a \qquad \text{(lb. per sq. in.)}$$

Illustrative Problem.—A tank has been filled with air to an initial air pressure of 10 lb. and is then filled one-fourth with water. What is the air pressure on the tank? Here P_i = 10 lb., F = 0.25, 1.00 − F = 0.75.

$$\frac{15 + 10}{0.75} - 15 = 18.33 \text{ lb. per sq. in.} = P_d$$

Given a tank partly filled with water under pressure to find the remaining pressure when a given volume of water is drawn:

$$P_o = \frac{1.00 - F\,(P + P_a)}{(1.00 + f - F)} - P_a \qquad \text{(lb. per sq. in.)}$$

Illustrative Problem.—A tank is three-fourths filled with water under 45 lb. air pressure. What is the remaining pressure when one-fourth the volume of the tank is drawn? P = 45 lb., F = 0.75, f = 0.25

$$P_o = \frac{(1.00 - 0.75)(45 + 15)}{1.00 + 0.25 - 0.75} - 15 \quad 15 \text{ lb. per sq. in.}$$

Given a tank partly filled with water under a given pressure to find the volume of water that may be drawn for a given drop in pressure.

$$f = \frac{P_1\,(1.00 - F)}{P + P_a - P_1} \qquad \text{(percent of volume)}$$

Illustrative Problem.—A tank three-fourths filled with water is under a pressure of 45 lb. What percentage of water may be drawn for a drop in pressure of 30 lb.? P = 45 lb., P_1 = 30 lb.

$$f = \frac{30(1.00 - 0.75)}{45 + 15 - 30} = \frac{7.5}{30} = 25\%$$

The above formulas and illustrative problems are general and apply to any tank filled to any percent of its volume, whereas the following illustrative problems apply to tanks ⅔ full of water.

Illustrative Problem.—A 630-gal. tank, 36 in. × 12 ft., is ⅔ full of water under a pressure of 60 lb. How much water can be drawn lowering pressure to 20 lb.?

Between 60 and 20 lb., Table 42 gives 38 %. Therefore, 0.38 × 630 = 239 gal. can be drawn.

Illustrative Problem.—What size tank must be used to deliver 500 gal. of water from storage when ⅔ full, under 80 lb. pressure, if lowest water pressure must be 30 lb.?

Between 80 and 30 lb., Table 42 gives 37 %. Tank must therefore be 500 + 0.37 = 1350 gal. capacity, or about 48 in. × 14 ft.

Illustrative Problem.—A 720-gal. tank 42-in. × 10 ft. is ⅔ full of water under a pressure of 50 lb. What is the water pressure after 150 gal. have been drawn?

150 gal. = 21 % of tank capacity. Corresponding to 50 lb. initial pressure and 21 % working capacity, Table 42 gives final water pressure of 25 lb.

Note: If tank is only one-half full of water, working capacity is increased 50 %.

Notation for Formulas for Pneumatic Tanks

P_a = atmospheric pressure of air in lb. per sq. in., usually taken at 15 lb.
P_i = initial air pressure in lb. per sq. in. above P_a, put in tank before water enters.
P_d = desired pressure after tank is filled with air to P_i lb., then partly filled with water.
P = air pressure in tank before water is drawn.

Table 42.—Working Capacity of Pneumatic Tanks in Percentage of Full Volume when Two-thirds Full of Water. Between Initial and Final Pressures Indicated

Final pressure, pounds gage	Initial pressure—pounds gage									
	10	20	30	40	50	60	70	80	90	100
5	8	25	41	58						
10	0	13	26	40	53	66				
15		5	16	28	39	50	61			
20		0	9	19	29	38	48	57		
25			6	12	21	29	37	46	54	62
30			0	7	15	22	30	37	44	52
35				3	10	17	23	30	37	43
40				0	6	12	18	24	30	36
45					3	8	14	19	25	30
50					0	5	10	15	20	25

Table 43.—Showing Pressure in Pneumatic Tanks when Filled with Various Quantities of Water

Amount of water pumped into tank	Pressure (pound per square inch) no initial pressure	Pressure (pound per square inch) with 10 lb. initial air pressure
¼ full of water	5	18
⅖ full of water	10	26
½ full of water	15	34
⅗ full of water	22	47
⅔ full of water	29	58
¾ full of water	45	83

P_0 = air pressure in tank after water is drawn.
P_1 = loss in pressure due to drawing any percent of volume of tank.
F = portion of volume of tank filled with water.
f = amount of water drawn from tank in percent of its volume.

56. Heat Required to Free Tanks from Ice.—It requires from 2½ to 3 heat units per square foot of exposed surface per degree difference in temperature per hour to keep an exposed steel tank free from ice.

Illustrative Problem.—What is the total quantity of heat required to free a tank 10 ft. high by 20 ft. in diameter for 24 hr. from ice, when the temperature of air is 10 deg. F.?

Surface of tank = $\frac{2\pi 20^2}{4} + (\pi 20)(10)$ 1256.6 sq. ft.

Heat units = 3(32 + 10)(24)(1256.6) = 3,799,958. At 9000 heat units per pound of coal it would require 3,799,958 ÷ 9000 = 422.2 lb. of coal.

It is thus seen that it is not at all economical to attempt to keep large tanks from freezing by heating. It is more economical to protect them either by housing, or by circulating water of a higher temperature than that from a well, than it is to let the tank stand full exposed to the cold and attempt to heat it.

If the above tank were filled with water each 24 hr. at a temperature of 44 deg. F., the amount of heat energy brought to the tank by the water would be equal to 23,500 (gallons) × 8⅓ × 12 = 2,350,000 heat units, or slightly over ½ that required to heat the tank if allowed to stand full of water without changing daily. Where the tank is supported on an inclosed structure and the top weatherproofed with deck floor and roof, the exposed surface is naturally cut down and therefore less heat is required. Elevated steel tanks usually freeze first at the connection with the riser pipe.

PIPES AND FITTINGS

57. Cast-iron Pipe.—Cast-iron pipe is now manufactured in standard diameters and weights, as class "*A*," "*B*," and "*C*," Table 44 These are in accord with the standard specifications of the American Waterworks Association. In specifying cast-iron pipe it will only be necessary to state size and class desired.

TABLE 44.—DIMENSIONS AND WEIGHTS OF AMERICAN WATERWORKS STANDARD CAST-IRON PIPE

Nominal inside diameter (inches)	Class "*A*" 100-ft. head 43-lb. pressure			Class "*B*" 200-ft. head 86-lb. pressure			Class "*C*" 300-ft. head 130-lb. pressure		
	Thickness (inches)	Weight per Foot (pounds)	Weight per Length (pounds)	Thickness (inches)	Weight per Foot (pounds)	Weight per Length (pounds)	Thickness (inches)	Weight per Foot (pounds)	Weight per Length (pounds)
4	0.42	20.0	240	0.45	21.7	260	0.48	23.3	280
6	0.44	30.8	370	0.48	33.3	400	0.51	35.8	430
8	0.46	42.9	515	0.51	47.5	570	0.56	52.1	625
10	0.50	57.1	685	0.57	63.8	765	0.62	70.8	850
12	0.54	72.5	870	0.62	82.1	985	0.68	91.7	1100

58. Wrought-iron Pipe.—Wrought-iron pipe, unless otherwise specified, will be "Merchant" steel pipe, black. If strictly wrought-iron pipe is desired, specify *strictly wrought-iron pipe* or "*Buyers*" *wrought-iron pipe.*

Merchant pipe is much harder to cut or thread and is much shorter lived than strictly wrought-iron pipe. On the other hand, the latter is much higher in price and more difficult to obtain.

The steel pipe is about 2 % heavier than wrought-iron pipe for the same thickness. Both qualities of pipe are manufactured in *standard* and *extra heavy weights.*

TABLE 45.—DIMENSIONS AND WEIGHTS OF STANDARD WROUGHT-IRON PIPE AND COUPLINGS

Standard wrought-iron pipe: Size	Weight per foot (pounds)	Thickness (inches)	Couplings: Diameter	Length	Weight
½	0.84	0.109	½	1⁵⁄₁₆	0.124
1	1.67	0.133	1	1¹³⁄₁₆	0.455
1½	2.68	0.145	1½	2⅜	0.800
2	3.61	0.154	2	2⅝	1.250
2½	5.74	0.203	2½	2⅞	1.757
3	7.54	0.216	3	3⅛	2.625
3½	9.00	0.226	3½	3⅝	4.000
4	10.66	0.237	4	3⅝	4.125
4½	12.34	0.246	4½	3⅝	4.875
5	14.50	0.259	5	4⅛	8.437
6	18.76	0.280	6	4⅛	10.625
7	23.27	0.301	7	4⅛	11.270
8	28.18	0.322	8	4⅛	15.150
9	33.70	0.354	9	5⅛	17.820
10	40.06	0.366	10	6⅛	27.700

59. Wood Stave Pipe.—Wood stave pipe is made in two ways—continuous stave pipe made in the trench, and machine banded pipe, factory made. Continuous stave pipe is used almost exclusively in the Western States where the climatic conditions are suitable and where suitable timber may be had. This pipe in several instances has proven a failure due to soil conditions, character of wood, workmanship, etc.; therefore, before it is used, a careful investigation should be made to determine if it will prove satisfactory. Machine banded wood stave pipe is made in lengths up to 12 ft., staves being machined on the sides to correct bevel to suit size. These staves are also provided with double tongues and grooves, and the outside is formed to diameter of pipe. The staves are held in place by galvanized steel bands or wire spirally wound from end to end. The outside of the pipe and steel bands are protected by a double coat of asphaltum and sawdust.

Table 46.—Trade Data on Machine Banded Wood Stave Pipe

Size of pipe	Weight per linear foot	Number of feet in carload	Men required to lay pipe	Number of feet can be laid in 10 hours	Wood stave pipe	Cast iron
					Comparative cost of laying pipe per foot not including trenching and back filling	
6	11.5	2600	6	2500	0.01	0.14
8	14.6	2100	6	2500	0.02	0.17
10	18.6	1700	6	2000	0.03	0.20
12	20.8	1500	6	2000	0.03	0.23
14	25.5	1200	6	2000	0.04	0.26
16	28.6	1000	6	1500	0.04	0.36
18	31.7	850	6	1500	0.04	0.40
20	36.5	650	6	1000	0.05	0.50
24	45.6	500	8	1000	0.06	0.62
30	57.3	300	8	1000	0.07	0.75
36	76.8	200	8	800	0.08	1.05
48	103.0	150	8	600	0.10	1.29

Table 47.—Weight per Foot of Lead Service Pipe in Pounds and Ounces

Extra strong

Size of Pipe in Inches

3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4
2-0	2-8	3-0	3-8	4-12	6-0	7-8	9-0	14-0	16-0	18-0	21-0

The joints are made on the mortise and tenon principle, and are driven together by heavy ram or hammer while in the trench. This pipe does not have to be laid perfectly straight, but can be slightly curved in any direction. Connections can be made to it by cast-iron fittings with hubs turned to fit the spigot of the wood stave pipe. The carrying capacity of this pipe is about 14 % greater than cast-iron pipe.

Wood stave pipe gives good satisfaction where first-class materials and workmanship are had, but it should not be used where it will not always be kept wet; where frost will heave it continuously; or where there is a considerable amount of air entrained with the water. It is made to stand pressures up to 100 lb. per sq. in. if satisfactorily machine banded.

60. Cost of Laying Pipe.—The data in Tables 48 and 49 were compiled from table given in *Engineering and Contracting*, Vol. 51, pp. 37 and 38. The data were obtained on the laying of gas pipe, but it would apply equally well for water pipe. These prices should not be applied

to rock, hardpan, or quicksand excavation, but only to cases which might be considered as *average* excavation. For depths greater than 6 ft., the cost of excavating increases more nearly with the square of the depth than directly with it.

TABLE 48.—COST OF TRENCHING, LAYING, JOINTING AND BACKFILLING CAST-IRON PIPE

Size of pipe	Cost of trenching 100 ft. @ 0.01 per man hour 1 ft. deep	Cost of bell holes on 100 ft. @ 0.01 per man hour (pounds)	Weight of pipe per foot	Feet of pipe laid per man hour	Cost of laying 100 ft. @ 0.01 per man hour	Weight of lead per joint (pounds)	Weight of yarn per joint (pounds)	Joints made per man hour	Cost jointing 100-ft. pipe @ 0.01 per man hour	Cost of pipe per 100 ft. @ $1.00 per ton	Cost of lead per 100 ft. of pipe @ 0.01 per pound	Cost of yarn per 100 ft. of pipe @ 0.01 per pound	Cost of drayage per 100 ft. @ $1.00 per ton mile
4	$0.184	$0.045	19.33	21.98	$0.0455	6	0.37	6.25	$0.0405	$0.966	$0.50	$0.0308	$0.966
6	0.203	0.051	30.25	14.05	0.0711	9	0.47	4.16	0.0601	1.512	0.75	0 0301	1.512
8	0.222	0.057	42.08	10.09	0.0991	12	0.56	3.12	0.0801	2.104	1.00	0.0466	2.104
10	0.239	0.060	55.91	7.60	0.1316	16	0.65	2.34	0.1068	2.796	1.33	0.0541	2.796
12	0.277	0.066	73.83	5.75	0.1730	22	0.75	1.70	0.1470	3.691	1.83	0.0625	3.691
16	0.333	0.078	112.58	3.77	0.2652	36	1.06	1.03	0.2427	5.630	3.00	0.0883	5.630
20	0.369	0.087	153.83	2.76	0.3623	50	1.34	1.25	0.3333	7.777	4.16	0.1116	7.777
24	0.406	0.096	206.41	2.06	0.4854	62	1.60	1.04	0.4006	10.320	5.16	0.1333	10.320
30	0.461	0.111	281.00	1.49	0.6711	75	2.00	0.83	0.5020	14.204	6.25	0.1666	14.204

To use cost prices for trenching and backfilling, multiply cost by depth of trench and by local cost of labor per man hour. For other labor costs, multiply by man hour price for that class. For material, multiply by cost pounds or ton as specified.

TABLE 49.—COST OF TRENCHING, LAYING, JOINTING AND BACKFILLING FOR WROUGHT-IRON AND STEEL PIPE

Size of pipe	Weight of pipe per foot in pounds	Feet of pipe laid per man hour	Cost of laying 100 ft. at 0.01 per man hour	Width of trench (inches)	Cost of excavation and backfilling 100 ft. pipe 1 ft. deep at 0.01 per man hour	Cost jointing per 100 ft. pipe per man hour	Cost for drayage for 100 ft. pipe at $1.00 per ton mile
1¼	2.28	104.2	$0.0096	18	$0.166	$0.0111	$0.114
1½	2.73	86.6	0.0116	18	0.166	0.0125	0.136
2	3.68	65.0	0.0154	18	0.166	0.0166	0.184
3	7.62	36.6	0.0273	18	0.166	0.0250	0.381
4	10.89	26.6	0.0376	20	0.184	0.0333	0.544
5	19.19	15 8	0.0633	22	0.203	0.0500	0.959
6	28.81	10.5	0.0952	24	0 222	0.0750	1.440

Apply same multiplier as for cast-iron pipe. No bell holes are allowed for here.

61. Concrete Pipe.—Concrete pipe is manufactured, but not extensively, in sizes from 4- to 120-in. diameter. In some localities the small sizes are in competition with vitrified pipe for sanitary sewers, but its principal use is in the larger sizes (from 36 to 120 in.) for storm sewers and culverts. These sizes are usually made on the site of the work, but can be shipped readily where necessary. Railroad companies often make them in one or two yards and ship to points on the system for culvert use.

Table 50.—Trade Information on Reinforced Concrete Pipe in 4-ft. Lengths

Size (inches)	Thickness (inches)	Steel (pounds per square foot)	Cross sectional area of steel (square inches per foot of shell)	Weight of pipe per foot
24	2½ - 3	0.30	0.058	264
27	3 - 3½	0.30	0.068	350
30	3½	0.40	0.080	384
33	4	0.50	0.107	485
36	4	0.60	0.146	524
39	4¼	0.60	0.146	580
42	4½	0.60	0.153	686
48	5	0.80	0.107	866
54	5½	0.80	0.126	1070
60	6½	0.90	0.146	1295
72	7	1.00	0.180	1810
78	8	1.30		2250
84	8	1.30	0.208	2400
90	8¼	2.12		2550
96	8½	2.60	0.245	2650
102	9	3.02		
108	9			2900
114	9½			
120	10			

In sizes from 24 to 42 in., 1 ring of steel is used.
In sizes from 48 to 120 in., 2 rings of steel are used.

The carrying capacity of these pipes of large diameter is slightly greater than for vitrified pipe of the same diameter. The cost will depend upon the availability of the materials at the desired location.

The head carried on concrete pipe should not exceed from 100 to 125 ft. and leakage due to this pressure in properly constructed pipe should not be greater than in pipe made of other materials. The coefficient of discharge is higher than that for steel pipe.

62. Standard Flange Fittings.—In Table 51 are given the specifications for "American Standard" flanged fittings for wrought-iron and steel pipe. Dimensions apply to low pressure and standard fittings not extra heavy.

Notes on the American Standard.—The following notes apply to the American Standard for flanges and flanged fittings.

(*a*) Standard reducing elbows carry the same dimensions center to face as regular elbows of largest straight size.

Standard tees, crosses, and laterals, reducing on run only, carry same dimensions face to face as largest straight size.

Standard weight fittings are guaranteed for 125-lb. working pressure and extra heavy fittings for 250 lb.

The size of all fittings scheduled indicates the inside diameter of parts.

The face-to-face dimensions of reducers, either straight or eccentric for all pressures, are the same as those given in table of dimensions.

Twin elbows, whether straight or reducing, carry same dimensions center to face and face to face as regular straight-size ells and tees.

Side outlet elbow and side outlet tees, whether straight or reducing sizes, carry same dimensions center to face and face to face as regular tees having same reductions.

(*b*) Bull-head tees, or tees increasing on outlet, have same dimensions center to face and face to face, as a straight fitting of the size of the outlet.

(*c*) For fittings reducing on the run only, always use the long-body pattern. Y's are special and are made to suit conditions.

TABLE 51.—STANDARD FLANGE FITTINGS

Size in 1 inch to 12 inches	Diameter flanges	Thickness flanges	Diameter bolt circle	Number of bolts	Face to face. Tees and crosses	Center to face. Ells, tees and crosses	Center to face. 45° elbow s
1	4	7/16	3	4	7	3 1/2	1 3/4
1 1/4	4 1/2	1/2	3 3/8	4	7 1/2	3 3/4	2
1 1/2	5	9/16	3 7/8	4	8	4	2 1/4
2	6	5/8	4 3/4	4	9	4 1/2	2 1/2
2 1/2	7	11/16	5 1/2	4	10	5	3
3	7 1/2	3/4	6	4	11	5 1/2	3
3 1/2	8 1/2	13/16	7	4	12	6	3 1/2
4	9	15/16	7 1/2	8	13	6 1/2	4
4 1/2	9 1/4	15/16	7 3/4	8	14	7	4
5	10	15/16	8 1/2	8	15	7 1/2	4 1/2
6	11	1	9 1/2	8	16	8	5
7	12 1/2	1 1/16	10 3/4	8	17	8 1/2	5 1/2
8	13 1/2	1 1/8	11 3/4	8	18	9	5 1/2
9	15	1 1/8	13 1/4	12	20	10	6
10	16	1 3/16	14 1/4	12	22	11	6 1/2
12	19	1 1/4	17	12	24	12	7 1/2

63. Standard Screwed Fittings.—The center to end dimensions of ells, tees, and crosses for same size of opening are alike. The dimensions of ells, tees, and crosses for malleable and cast iron from 1/4 to 4 in., are practically identical. In Table 52, dimensions and weights are for malleable fittings from 1/4 to 4 in. and for cast iron from 4 to 8 in

TABLE 52.—SCREWED FITTINGS
Weights in pounds per 100

Size 1/4 in. to 4 in. Mal. 4 in. to 8 in. C.I.	End to end. Tees and crosses	Center to end. Tees, ells and crosses	Center to end. 45° ells	Ells	45° ells	Tees	Crosses
1/4	1 5/8	13/16	3/4	13	11	14	
3/8	1 7/8	15/16	13/16	17	14	23	21
1/2	2 1/4	1 1/8	7/8	27	21	35	42
3/4	2 5/8	1 5/16	1	39	32	55	54
1	2 7/8	1 7/16	1 1/8	60	50	80	96
1 1/4	3 1/2	1 3/4	1 5/16	105	80	136	152
1 1/2	3 7/8	1 15/16	1 7/16	131	111	183	197
2	4 1/2	2 1/4	1 11/16	232	197	285	340
2 1/2	5 3/8	2 11/16	1 15/16	420	350	428	575
3	6 1/4	3 1/8	2 3/16	637	483	742	960
3 1/2	6 7/8	3 7/16	2 3/8	910	665	1000	1040
4	7 1/2	3 3/4	2 5/8	1100	775	1200	1550
4 1/2	8 1/8	4 1/16	2 13/16	1600	1450	2330	2700
5	8 7/8	4 7/16	3 1/16	2100	1650	2620	3000
6	10 1/4	5 1/8	3 7/16	3000	2500	4000	4300
7	11 5/8	5 13/16	3 7/8	4400	3500	5500	6000
8	13	6 1/2	4 1/4	5500	4600	7900	8300

SECTION 3

SEWAGE DISPOSAL

BY W. G. KIRCHOFFER

It is not intended in this section to give a complete treatise on this subject. For full up-to-date information the reader is referred to standard works on sewage disposal, such as American Sewage Practice by Metcalf and Eddy, Sewage Disposal by Fuller, or Sewage Disposal by Kennicutt, Winslow and Pratt. The descriptions of the processes herein given are intended to convey only a general notion of the principles under which the processes will work. The designer of an isolated plant will then have a reasonably good idea of what he can expect, if he attempts to do certain things with sewage.

COLLECTION AND FLOW OF SEWAGE

1. Size of Sewers.—The size of a sewer should not be based upon the average flow anticipated, but upon the maximum rate of flow that can reasonably be expected to take place daily. It can be inferred that the flow of sewage would follow quite closely the consumption of water and would reach a maximum of about 175% of the mean flow (see Fig. 2, p. 1258). It is quite a common rule to assume that the maximum will be twice the minimum so that if the sewer is designed to flow half full with mean flow, it will be large enough for maximum flows.

If it is expected that an increase in the discharge of sewage will take place in the near future, due to additional building or increase in the industrial waste, it would be advisable to design the sewers for three times the mean flow. Table 1 has been prepared on such an assumption.

For other grades than those given, the capacity is proportional to the square root of the slope. The population served by a given sewer would be inversely proportional to the amount of sewage contributed to the sewer by that population, as compared with the figures given in the table.

TABLE 1.—POPULATION THAT CAN BE SERVED BY SEWERS WITH VARIOUS GRADES
Based on a consumption of 100 gallons per capita per day. Sewers assumed running one-third full. $n = 0.013$

Size sewer (inches)	Fall of sewer in feet per 100 feet								
	0.5	0.4	0.33	0.25	0.20	0.167	0.125	0.10	0.083
6	1,060	930	850	690	530				
8	2,160	1,945	1,730	1,405	1,200	1,000	860	720	
10	3,780	3,460	3,070	2,640	2,130	2,260	1,940	1,470	
12	5,340	4,970	4,540	4,140	3,600	3,240	2,850	2,550	2,370
15	9,360	8,360	7,560	6,560	6,000	5,400	4,400	4,240	3,880
18	15,500	13,850	12,600	11,000	9,940	8,930	7,540	7,000	6,230
20	19,250	18,200	16,750	14,400	13,250	11,700	10,150	9,340	8,320
24	33,800	30,500	27,700	24,000	21,800	18,800	16,920	15,400	13,700

2. Materials Used for Sewers.—The universal material used for sewers is vitrified clay pipe. Sewers 30 in. diameter and larger are often built of brick, reinforced concrete, cast iron, or wrought iron. Sometimes wood stave pipe is used where soils will not support vitrified pipe

satisfactorily, where the sewer is under pressure, or where leakage would pollute a water supply. Vitrified pipe in lengths of 2, 2½, and 3 ft. can be purchased in sizes from 4 to 30 in. (advancing by 2 in. to 12 in. and thereafter by 3 in.). 2- and 2½-ft. lengths are most common.

3. Limiting Grades.—The minimum grade of a sewer is fixed by the velocity at which it will be self-cleansing, usually assumed at 2 to 3 ft. per second; greasy wastes would require greater velocities. Flushing is the only safe way to be sure of a clean and sanitary sewer. For small lateral sewers a grade of 1 ft. in 200 ft. is very satisfactory but where conditions will not permit, a grade of 1 ft. in 400 ft. is permissible. Sewers 24 to 30 in. in diameter with a flow of sewage sufficient to fill them one-half or more full, are often laid on a grade of 1 in 1000 or 1 in 1200 ft.

4. Workmanship.—The construction of sewers is more likely to be neglected than any other part of a building contract. "Out of sight, out of mind" is often too true. It is highly important that the sewer should be laid to a straight line and grade, with joints even and well filled with a hemp gasket and cement mortar. Stoppages in sewers are often caused by poor workmanship in the laying. The capacity can also be materially cut down by a crooked rough sewer.

5. Details.—The appurtenances of a common ordinary sewer are manholes, lampholes, and flush tanks. No sewer should be constructed, no matter how short, that does not have at least one manhole on it. On longer sewers they should be spaced 300 to 500 ft. apart depending on local conditions, size of sewers, character of sewage, and funds available for the work.

A manhole to be serviceable should be 3 to 4 ft. in diameter and extend from sewer to surface of the ground or street and be provided with an iron or concrete cover, readily removable. They can be constructed of brick, concrete, or cement blocks. The invert of the sewer should be continued through the manhole just the same as in the sewer, only the top half of the pipe should be cut away to allow for inspection and cleaning.

Lampholes are not used as much as formerly. They are for the purpose of flushing the end of a sewer with a hose, or to permit the lowering of a light in case of obstruction. They are made of sewer pipe and have an iron cover.

Flush tanks are not likely to be needed on sewers for a single building, but should be included where the system is extensive or has very flat grades. These tanks should be located so as to flush the greatest lengths of sewers on the flattest grades. A flush tank is usually a small reservoir or cistern provided with an automatic syphon for the discharge from the tank and an orifice for control of the water used for flushing. The water is usually obtained from the city water mains, but may be obtained from a private source of supply as the case may demand.

6. Variations of Flow.—The variations in the volume of sewage discharged from any building or industry will follow quite closely the hourly variations in the consumption of water. The curves shown in Fig. 2, p. 1258, will therefore fairly represent the relative (not absolute) volume of flow of sewage from one hour of the day to another. Where large quantities of ground water enter the sewer through the joints or otherwise, or where large volumes of cooling or wash water are constantly turned into the sewer, the relative variation will be very much smaller.

7. Cost.—There are many factors that affect the cost of sewers, such as the nature and condition of the soil, price of labor and materials, diameter of pipe, and depth of trench. Table

TABLE 2.—FOR ESTIMATING COST OF VITRIFIED PIPE SEWERS

Depth of trench in feet

		4	5	6	7	8	9	10	11	12	14	16	18	20
Size of pipe (inches)	6	0.40	0.45	0.50	0.58	0.65	0.75	0.85	0.98	1.08	1.35	1.68	2.03	2.43
	8	0.53	0.58	0.63	0.70	0.80	0.88	1.00	1.10	1.23	1.53	1.85	2.23	2.65
	10	0.65	0.73	0.78	0.85	0.95	1.05	1.15	1.28	1.40	1.70	2.13	2.45	2.90
	12	0.83	0.88	0.95	1.03	1.13	1.23	1.33	1.45	1.60	1.93	2.28	2.70	3.18
	15	1.10	1.15	1.23	1.30	1.40	1.53	1.65	1.78	1.93	2.28	2.68	3.13	3.63
	18	1.40	1.45	1.53	1.63	1.73	1.85	2.00	2.15	2.30	2.68	3.10	3.60	4.15
	20	1.63	1.70	1.78	1.88	2.00	2.13	2.25	2.43	2.60	3.00	3.45	3.95	4.55

2 has been prepared from the bids on many sewers. These bids were compiled during a period of 20 yr. and represent average conditions. The prices have been made to cover the approximate recent (1927) prices. They should be used only as a guide and should be increased where the local conditions are unfavorable to average working conditions. The table does not cover rock excavation or quicksand digging.

COMPOSITION OF SEWAGE

8. General Characteristics.—Sewage has been defined as a combination of the liquid waste conducted away from residences, public and business buildings, and industrial establishments. A briefer definition would be, "The wastes of human habitation." It possesses three general characteristics as suggested by Prof. E. B. Phelps: the physical property of "concentration," the chemical property of "composition," and the biological property of "condition." A sewage containing a large proportion of sewage matter as compared to the water of a given sewage, is strong or concentrated, while one having the reverse of these conditions is a weak or dilute sewage.

A concentrated sewage means that a greater quantity of sludge will be produced which must be cared for, and it also means that the solids will settle out quicker than in a dilute sewage.

The particular process to adopt for the treatment of a given sewage depends more upon the composition of the sewage matter than upon the concentration or condition. When a sewage is in a "fresh" condition it lends itself more readily to oxidizing processes, whereas a stale sewage or one that has traveled a long ways in pipes or stood in receiving basins, lends itself more readily to septic action.

9. Total Solids.—A weak or dilute sewage contains about 200 parts of solids to each million parts of sewage; a medium or average sewage, about 800 parts; and a strong sewage about 1600 parts per million. The total solids in sewage are divided physically into suspended and dissolved matters, and chemically into organic and mineral matters. The subdivision of the total solids of a typical American sewage are shown in the accompanying diagram.

PHYSICAL CONDITION OF PRINCIPAL CONSTITUENTS OF SEWAGE OF MEDIUM STRENGTH
(Numbers are parts per million)

Total solids 800	Suspended solids 300 (by filter paper)	Settling solids (2 hr.) 150	Organic settling solids 100	150 settling solids	Total solids 800
			Mineral settling solids 50		
		Suspended colloidal solids 150	Organic suspended colloidal solids 100	200 colloidal solids	
			Mineral suspended colloidal solids 50		
	Dissolved solids 500	Dissolved colloidal solids 50	Organic dissolved colloidal solids 40		
			Mineral dissolved colloidal solids 10		
		Dissolved crystalloidal solids 450	Organic dissolved crystalloidal solids 160	450 crystalloidal solids	
			Mineral dissolved crystalloidal solids 290		

10. Organic Matter.—The organic matter in a typical sewage is divided approximately as follows:

- Organic matter 400
  - Nitrogenous 150
    - Nitrogen 15
    - Carbon 75
    - Hydro. oxygen
    - Sulphur phosphate 60.
  - Non-nitrogenous 250
    - Fats 50
      - Carbon 35
      - Hydrogen, Oxygen 15
    - Carbohydrates 200
      - Carbon 90
      - Hydrogen, Oxygen 110

Organic matter is of vegetable and animal origin. It is the part of the solids in sewage in which we are particularly interested from a sanitary standpoint. Nitrogenous matter, consisting principally of urea and proteids, is generally considered as the substance that is the least stable and most likely to break down and cause a nuisance. Offensive gases are usually of a sulphurous origin.

11. Mineral Matter.—Mineral matter consists principally of calcium and magnesium carbonates and sulphates. Where the water supply used in producing the sewage is highly mineralized, the sewage is likely to be mineralized also. Industrial wastes often contain mineral matters that affect the mineral constituents of sewage. These matters in themselves are not objectionable from a sanitary standpoint, but often if in large quantities and combinations, they interfere with the processes of purification.

12. Suspended and Settling Solids.—All solids in sewage which are floating, suspended by virtue of the velocity of the liquid, and those that are in a colloidal state, are defined as suspended matter. Settling solids are those that will settle out of solution in 2 to 4 hr. after quiescence begins. It is important in the treatment of industrial wastes to remove as large a percentage of settling solids as possible. The higher the total suspended matter present, especially if it be of a coarse material, the greater will be the percentage of the settling solids removed. Colloids are difficult to remove by settling. They are in a semi-soluble state. Some matters of a fatty or soapy nature will not settle out although they remain in a strictly suspended condition.

13. Putrefaction.—Organic matter contained in sewage soon begins to putrefy due to a lack of oxygen. Where oxygen is present or can be supplied in sufficient quantities, the reduction of this material goes on in an aerobic condition, but where sufficient oxygen is lacking, the reduction goes on in an anaerobic condition. An effluent from a sewage disposal plant that is not putrescible is said to be stable. One of the most common and reliable tests for this is the methylene blue test.

14. Bacterial Action on Organic Matter.—There are two separate and well defined processes of bacterial action that take place in sewage. When sewage first reaches the public sewers it is "fresh" and contains free oxygen so that *aerobic* bacteria thrive. These bacteria grow and multiply only in the presence of oxygen. After sewage has traveled a long distance in sewers or has stood quiescent in a tank for sometime, the sewage becomes stale or septic when *anaerobic* bacteria, those that grow in the absence of oxygen, come into evidence as the chief factor in the reduction of the organic matter.

The processes are diametrically opposite and opposed to each other. The aerobic or oxidation process is accompanied with little or no odor while the opposite is very true of the anaerobic or septic process.

Unless oxygen is supplied in sufficient quantities and quick enough, the sewage will invariably pass into the septic state from which it is difficult to again restore it to an oxidized condition.

For small plants it is difficult to prevent some septization from taking place without an unwarranted expense for installation and operation. In fact, it is usual in most plants to allow the sewage to get into a more or less septic state before attempting to apply methods of oxidation. Some of the more recently designed tanks and processes are planned to completely, or at least to a very large extent, prevent septic action. Such processes are particularly desirable to use where a high degree of purity is necessary.

PROCESSES OF PURIFICATION

15. Dilution.—No hard and fast rule can be laid down by which it may be determined that sewage disposal by dilution will be satisfactory and not cause a nuisance. Some authorities have used the rule that if there were 5 cu. ft. of water flowing per second in the stream per thousand population tributary to the sewer, a nuisance would not be created. The rule will not hold good in most instances.

The changes that take place in the dilution method are not materially different from those that take place in the process of filtration. It is largely a matter of oxidation accompanied by mechanical and physical agencies. For the process to be satisfactory there should remain no floating organic matter, no deposition of sludge should take place in the vicinity of the outlet, and there should be sufficient oxygen in the stream or other body of water to completely oxidize the sewage. As ordinarily spoken of, dilution has meant the disposal of raw sewage into a body or stream of relatively pure water. As actually practiced, the dilution method is used for the final disposal of all stages of sewage effluents from raw sewage to the effluents from the best slow sand filters.

It is a common practice, perhaps too common, to pass the sewage through tanks and then leave the balance of the process of purification to take place in the body of water into which the sewage passes, regardless of its size or condition. It is very obvious that raw sewage in considerable quantities, such as would be discharged from a large factory building or institution, should not be discharged into a small body of water or small stream. In almost all cases it is preferable to use some preliminary treatment to at least remove the floating solids and coarser matter. This can best be accomplished by screening or sedimentation in tanks.

The outlet sewer for best results should extend some distance into the water with several openings so as to provide a good intermingling of the sewage effluent with the water. It is a well established fact that streams will purify themselves under favorable conditions. The distance below the source of pollution that the stream may be found free from evidence of it, depends upon the relative volumes of sewage and water, upon the amount of oxygen present in the water, and upon the velocity of the stream. At New Orleans no traces of sewage pollution can be found in the Mississippi river, although the sewage of nine million people is discharged into it.

16. Screening.—Two classes of screens are used for this purpose: (1) coarse rack screens for removing objects that would obstruct machinery, render disposal waters unsightly, and prevent deposits on the bottom of rivers, lakes, and tidal waters, and (2) fine screens for the purpose of removing the above materials and also as much as possible of the finer suspended matter.

Coarse screens are built of bars ½ to 1½ in. apart, and fine screens, usually revolving, are built of perforated metal or wire cloth with holes seldom exceeding ¼ in. in size.

The use of fine screens can hardly be considered more than a very preliminary process. Screens are used principally where the ultimate disposal is into tidal waters or very large streams. Where a plant receives considerable attention from the caretaker, bar screens are advantageous on most any plant. None of the screens now made can compare with plain sedimentation for the removal of a large percentage of the settleable solids.

17. Sedimentation.—Sedimentation is the process by which sewage is allowed to stand quiescent in, or flow very slowly through, tanks or basins in which the settleable solids may subside to the bottom of the tank. This process, if carried out for a period of 2 to 3 hr. with the resulting sludge removed continuously or at frequent intervals, will not permit of much septic action. Such action is called *plain* sedimentation as it does not involve bacterial reduction or its attendant chemical changes. At least 150 parts per million of the solids of a typical sewage should be removed in 2 hr. Sedimentation is a valuable part of the process of disinfection of sewage as it has been proven that a disinfectant, such as liquid chlorine, will act much more effectively after the coarser matters have been removed.

The amount of matter that will settle varies greatly with different sewages and is largely influenced by quantity and character of industrial waste included in the sewage.

18. Tank Treatment.—There are three leading types of tanks for sewage treatment: (1) septic tanks, (2) Imhoff tanks, and (3) sedimentation tanks with auxiliary tanks for separate sludge digestion. Several other types have been proposed, such as the Travis and Dortmund tanks.

18a. Septic Tanks.—Septic tanks are really sedimentation tanks with the added feature that the sludge is retained in the tank for long periods of time to undergo anaerobic decomposition. As a result of this action, gas-lifted particles of sludge are raised to the surface of the liquid. These particles, while still in a partially decomposed state, are often carried away with the effluent, making it more turbid than the raw sewage. Such conditions frequently come about where the velocity of flow through the tank is suddenly changed to a high rate as would happen where storm water is allowed to get into sanitary sewers, or where there are relatively large changes in the discharge of sewage from the building. It is therefore advisable to keep out of the tank, storm waters and all other waters of variable flow that are relatively as pure as the effluent from the tank would be, such as cooling waters in condenseries, ice plants, etc. The relative variation of flow is usually greater for very small installations than for very large ones. For instance, the flow of sewage for a family of 3 people would likely vary 100% within 24 hr., whereas for a large factory running night and day the variation might be only 30%.

The size of a septic tank should be based on either the number of people served or upon the quantity of sewage flowing at the average rate (assume 24-hr. flow to take place in 18 hr.). The following tests applied to the design will usually bring satisfactory results for tanks of this type: (1) The capacity should be 4 cu. ft. to each person; (2) the capacity should equal about one-third of the volume of the daily flow; and (3) the rest period (flowing-through period) should be about 8 hr. The essential features of the design of a septic tank are: The inlet and outlets should be trapped so as not to disturb the floating sludge or allow it to flow away with the effluent. The velocity at entrance should be reduced as soon as possible to a minimum of about 11 ft. per hour and maximum of 30 ft. per hour. The tank should have a minimum depth of 4 ft. and should not be deeper than 12 ft., except in cases where it is necessary to get the required volume in a limited space. The length should be about twice the width. The tank may or may not be covered, but if covered it should not be air tight as the gases are liable to explode and do great damage. The tank should have some convenient means of cleaning—that is, by either drawing off the sludge or skimming the scum from the surface of the liquid. This feature is the one that is most likely to be neglected as it has been the general supposition that septic tanks do not need to be cleaned out at all, which is not in accord with the experience of the operation of the oldest tanks.

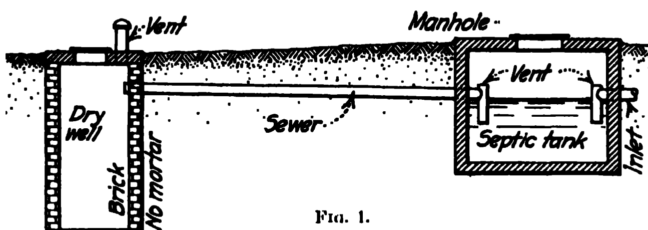


FIG. 1.

Fig. 1 illustrates a vertical, longitudinal section of a typical septic tank. The baffles at the inlet and outlet are usually made of an elbow or tee of vitrified pipe for small installations, and of plank or concrete hanging wall for large ones.

Septic tanks are made with hopper bottoms so that they can be cleaned out more easily, but the experience with these tanks has demonstrated that greater quantities of gas-lifted sludge are brought up into the liquid and hence into the effluent on account of the greater concentration of sludge at one point. The patent on the septic tank expired in 1916. Table 3 gives the proper dimensions of small tanks for 2 to 21 people.

TABLE 3.—DIMENSIONS OF SEPTIC TANKS

Number of persons served	Inside dimensions of tank for a given number of people		
	Width	Length	Depth
2 to 5	2 ft.–0 in.	4 ft.–0 in.	5 ft.–0 in.
6 to 9	2 ft.–6 in.	5 ft.–0 in.	5 ft.–0 in.
10 to 13	3 ft.–0 in.	5 ft.–0 in.	5 ft.–0 in.
14 to 17	3 ft.–0 in.	5 ft.–6 in.	5 ft.–0 in.
18 to 21	3 ft.–0 in.	6 ft.–0 in.	5 ft.–0 in.

18b. Imhoff Tanks.—Imhoff tanks were designed and patented by Dr. Imhoff of Essen, Germany. The design consists of a sedimentation tank superimposed on a septic tank for the digestion of the sludge. The flow takes place only through the upper tank and its bottom is so constructed with steep slopes and a baffled slot that the settleable solids slide into the digestion chamber below. This tank performs all the functions of a septic tank but keeps the process of sedimentation separate from the process of anaerobic decomposition of the sludge.

It is claimed that its principal advantage lies in the fact that the effluent is free from septic gas-lifted sludge; it also contains more oxygen and is, therefore, more readily treated subsequently by oxidizing processes, such as filtration. At the same time, it retains all the advantages of anaerobic decomposition of the sludge. The essential features of the design of an Imhoff tank are: a sedimentation chamber whose bottom has steep slopes and slot for passing settleable solids, and a sludge digestion chamber under the sedimentation tank with sludge pipe for removing the sludge. The inlets and outlets of the sedimentation chamber should be baffled and the bottom slopes should be not flatter than 1.5 units vertically to 1 horizontally. Flatter slopes have been tried but found to be unsatisfactory in most cases. These slopes should be made as smooth and even as possible. The slot between them should be not over 6 in. wide and properly baffled by extending edge of one slope past the slot, or in some other manner equally as good. Sufficient area must be provided for the escape of gas and for the floating sludge rising from the sludge chamber. Such gas vents on large plants should be extended several feet above the surface of the liquid in the tank.

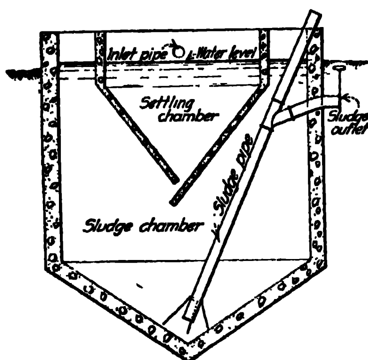


Fig. 2.

The sludge chamber should have bottoms sloping to one or more points from which the sludge can be removed. The slopes should be not flatter than 1 unit vertically to 3 units horizontally. A sludge pipe should extend to a point near the bottom so that some sludge may be removed. Removal of the sludge is usually accomplished by the head of water in the tank above the outlet of the sludge pipe, but where this is not possible, the sludge is pumped by a suction pump.

Fig. 2 illustrates a vertical cross-sectional view of a typical Imhoff tank showing the slopes, slot, sludge pipes, etc. The capacity of these tanks is based on the "flowing through period" for the upper story and on the volume of sludge produced by a given sewage for the lower story. The capacity of the sedimentation tank or upper story should be 1/4 to 1/6 of the volume of the 24-hr. flow, which would provide a rest period of 2½ to 3 hr., based on the average flow taking place in 18 hr. The capacity of the lower story or sludge chamber will depend largely upon the relative strength of the sewage and upon the frequency of drawing off sludge. An average value would be 0.008 cu. ft. per capita per day for a period of 3 mo. or more; that is, it should hold the sludge that would accumulate in 3 to 5 mo.

It is claimed that the Imhoff tank is an improvement over the septic tank in that it delivers a fresher and more uniform effluent and provides means for thoroughly digesting the sludge. However, Imhoff tanks are not giving the satisfaction as at first thought, or as claimed for them. Some of the principal difficulties and objections to them are: foaming of gas vents, which function spreads partially digested sludge all over the walls and surface of the sedimentation tank; scum forming on the surface of the sedimentation tank and becoming septic; settleable solids collecting on the sloping bottoms and becoming putrescible; generating of gas and sending sludge to the surface; difficulties in drawing off sludge by having it clog the pipe and cling to the sides and bottom of tank; liquid from upper story being drawn off in place of sludge, etc.

18c. Sedimentation Tanks.—Sedimentation tanks are similar to the Imhoff tanks in action and operation, but differ in construction. The sludge digestion tank, instead of being located under the sedimentation tank, is placed at one side of it. The sludge is drawn off periodically by a sludge pipe operating under the head of water in the sedimentation tank in a similar manner to the way in which sludge is drawn from the lower chamber of the Imhoff tank. This method is not entirely satisfactory as the sludge tank soon fills to a level near that of the settling tank, and then there is little or no head to produce a flow of the settling

solids, unless constructed at a much lower level. A much better plan is to pump the solids from the sedimentation tank by means of centrifugal or air lift pumps. The capacities of these tanks should be the same as for the corresponding stories of the Imhoff tank.

19. Filters.—The effluent from preliminary processes in most instances is further treated by filtration. There are four types of filters commonly used: (*a*) slow sand filters, (*b*) contact filters, (*c*) sprinkling or percolating filters, and (*d*) sub-surface filters or tile distribution.

19*a*. Slow Sand Filters.—Slow sand filters are constructed of a layer of medium coarse sand about 2 ft. thick, resting on a layer of gravel with under drains. The effluent from the tanks or other preliminary process is distributed over the surface by means of troughs or pipes in doses sufficient to cover the bed 2 in. deep. Sufficient time should elapse between doses to allow for complete drainage of the bed and for air to follow the liquid into the filter. The filter should be divided into three or more sections or beds, so that two beds can be operated alternately while the third one is resting and being cleaned of any surface deposit. The surface area of the filters in use should be so proportioned that they will receive from 5 to 10 gal. per sq. ft. per day. These filters should only be used where it is necessary to produce an effluent of high degree of purity.

19*b*. Contact Filters.—Contact filters are usually placed in large concrete tanks and consist of relatively coarse broken stone or gravel. The tank or other effluent is discharged into the filter periodically, filling the voids of the filter to nearly the surface of the stone. It is then allowed to stand in "contact" for a period of an hour or more when the effluent is drawn off for final disposal or further treatment. The filter is then allowed to stand empty for about 6 hr. when it is again filled as before. These filters are used principally in large installations as an intermediate process, but occasionally have been used for small installations, such as would be required for an isolated building, factory, or institution. The effluent from a contact filter or bed is far inferior to that of a slow sand filter and no better than that of a sprinkling filter. In some cases where extreme purification is not needed and where there is not sufficient head to operate filters of other types, this filter might prove to be the best solution of the problem. The rate of dosing is usually about 0.6 million gal. per acre per day with a minimum of 0.3 and a maximum of 1.0 million gal. per day. These beds are often operated in series, as primary and secondary.

19*c*. Sprinkling Filters.—The sprinkling filter is one of the newest and most satisfactory types of filters where an effluent of medium purity is satisfactory for further dilution in a stream or body of water.

The media used in these filters is crushed stone or gravel from ¾ to 2½ in. in size and in depth of 5 to 10 ft. The rate of operation varies from 1.5 to 2.0 million gal. per acre per day, depending upon the character of the applied effluent and the degree of purity desired. The removal of suspended matter and the stability of the effluent are both functions of the depth of the filter and the rate of application. The treated sewage is applied usually by means of spray nozzles automatically operated from a syphon chamber in which one or more automatic syphons are located. The rest period between doses need be only a few minutes, usually 15 to 30. From 4 to 9 ft. of head is required to operate the nozzles satisfactorily, which in some cases is a great objection to the use of this type of filter as such a head, together with the fall through the filter, could not be obtained without pumping. There is considerable odor noticeable about these filters, due to the spraying of a foul smelling liquid in the atmosphere. They should, therefore, be located as far as possible from inhabited buildings. This type of filter unloads its entrained organic matter in the form of humus.

The unloading may take place at frequent intervals, but principally in the spring of the year. If there is no provision made for catching the humus, the effluent at times will be very turbid and perhaps putrescible. It is therefore usual to provide a settling tank at the outlet of the filters in which the humus settles to the bottom. Such a reservoir should have a capacity equal to the volume of a 3-hr. flow. The humus must be removed frequently from the reservoir as it is highly putrescible and would gasify in a short time and pass off with the effluent if allowed to remain in the reservoir.

19*d*. Sub-surface Filters.—The sewage from many isolated residences, factories, institutions, etc., is disposed of by the use of sub-surface filters or tile drains laid in loose soils.

Some preliminary treatment must always be used to remove all of the coarser matters and as much as possible of the settleable solids which might eventually clog the tiles. For proper distribution of the liquid in the entire system, the tiling should be laid on very slight grades and all of the lateral lines should be on the same grade. The liquid should not be allowed to trickle into the main distribution pipe, but should be applied in doses sufficient to fill the system entirely full. This can be accomplished by the use of an automatic syphon. The amount of tile necessary will vary greatly with the character of the effluent to be handled and with the character of the soil absorbing the liquid, but will likely vary between 10 and 50 ft. of 4-in. tile per capita served.

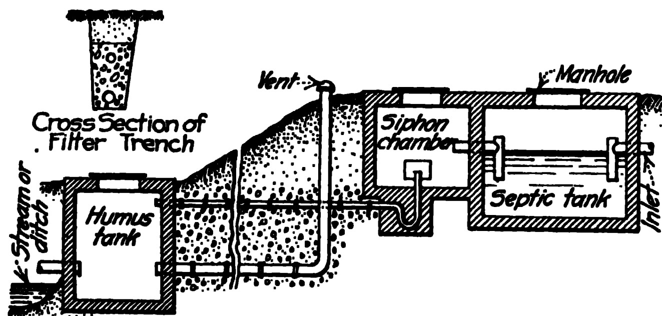


Fig. 3.

Where soil conditions are favorable and the amount of sewage to be cared for is relatively small, "dry wells" may be used to advantage for the disposal of tank effluents (see Fig. 1). In localities where the subsoil is not suited for absorption of the lliquid, it is sometimes necessary to artificially construct a sub soil about the drain tiles or in the form of a sub-surface filter (see Figs. 3, 4, and 5).

20. Broad Irrigation.—The broad irrigation process consists in irrigating agricultural land with the raw sewage or effluents from preliminary processes. This process can be very satisfactorily used in localities where the soil is very loose, such as sand or gravel which might be found in some of the warm climates. The method of application is by wooden troughs, pipes, or trenches made between two furrows. The latter method is usual where crops are raised on the sewage disposal area.

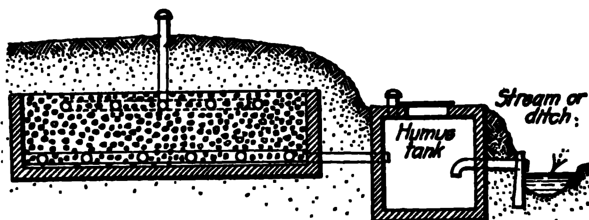


Fig. 4.

The rate of application will vary from 50,000 gal. per acre per day for a strong sewage and relatively fine sand, to one million ga'lons or more for a tank effluent on a coarse gravally soil. This is a method that is used quite commonly in warm climates where there is a sandy or gravelly soil available. It is also used in some northern cold climates where sand flats along large rivers are available for the purpose.

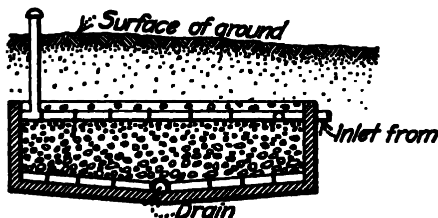


Fig. 5.

21. United States Public Health Service Design.—Prof. Earle B. Phelps and others of the Hygienic Laboratory of the United States Public Health Service, have experimented with a new type of plant for single houses or small communities. In a preliminary report they describe this most interesting design in part as follows:

The design consists of a concrete structure in which are placed an Imhoff tank with wooden partitions, bottom slopes, baffles, etc. In the second compartment is located a lath filter. It is built up of layers of ordinary laths, the

laths of adjacent layers lying at right angles to each other, and those of the same layer being parallel and spaced with clear openings of 3 in. The laths of alternate layers are so placed that they will come over the centers of the open spaces in the layer below. A filter 6 ft. deep yields an effluent of high degree of oxidation, and one 3½ ft. deep yields an effluent sufficiently oxidised to satisfy the requirements of most situations. A total filter volume of 8 cu. ft. per capita is required, or from 2½ to 12½ gal. of sewage may be applied to 1 cu. ft. per day.

The distributor consists of a tip trough similar to those used in rain gages. A cross section of this device is shown in Fig. 6. The trough extends entirely across the filter and discharges upon tapering boards placed upon the surface of the lath filter. As each compartment becomes nearly full the device is overbalanced and tips, rocking upon the supporting knife edge. The force of the impact is sufficient to cause the sewage to pass in a wave to the ends of the distributor boards. These boards are so tapered that the distribution over the entire area is rendered quite uniform. The performance of this filter is much superior to that of a good stone sprinkling filter. In 6-ft. depths with subsequent sedimentation, it is approximately equal to that of a well operated sand filter 2 ft. deep. Comparable results of this filter with a similar one of stone are given in Table 4.

TABLE 4.—AVERAGE PERFORMANCE OF LATH AND STONE FILTERS

	Lath	Stone
Rate (m g.a.d.)	2.90	3.12
Relatives stability of effluent (percent)	93.0	67.0
Reduction of biochemical oxygen demand (percent.)	89.0	81.0
Reduction of organic nitrogen (percent.)	55.0	29.0
Nitrogen oxidized (P.P.M.)	4.7	4.0

In the complete design, the sewage flows from the Imhoff tank through a pipe to the end of the distributor trough, and thence to the filters as above described. The effluent from the filter is again passed through an Imhoff tank located under the filter. The device fulfills in a most practical way the requirements of satisfactory operation with minimum superintendence.

It is claimed by the designers that a plant of this design, capable of caring for 10 people, can be built for $250. The degree of purification effected is sufficient for all purposes except where the discharge is directly into a water supply, in which case, chemical disinfection of the effluent is recommended in addition. In the northern sections of the country it will be desirable to provide heavy plank covers for protection against winter weather. The plant will operate without nuisance, and with a monthly inspection and semi-annual or annual removal of sludge from the tanks, will operate continuously without further attention.

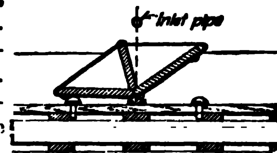


FIG. 6.

22. Selection of Method of Treatment.—It is common practice to discharge sewage and other wastes into large bodies of water and streams where such are available. This process of dilution, while correct in principle where properly applied, cannot be said to be a desirable one from an esthetic or sanitary standpoint. The installation of the simplest form of tank treatment will remove the principal objections to this process in many instances.

The choice of tank design is not always an easy matter to decide. Where the sewage is fresh and not broken up or digested, a Dortmund tank followed by an Imhoff, as shown in Fig. 7, should give most excellent results. Where a large factory or institution is to be served and the disposal plant is not a great distance from the power plant, or where electric current for power purposes is available, the plain sedimentation tank with separate sludge digestion tanks and air lift pumps should give satisfactory results (see Fig. 8).

Where the body of water or stream is relatively small or incapable of oxidizing the effluent to a stable condition, the tank treatment should be followed by some method of filtration. The type to select will depend upon local conditions as to final disposal and the amount of fall available. Where a partial purification will suffice and there is plenty of fall, a sprinkling filter will prove the most satisfactory, but under the same conditions with small fall, a contact filter should be used.

Where there is no body of water or stream in which to dispose of the final effluent, it must be disposed of underground by subsurface irrigation, a dry well, subsurface filter or by slow sand filters, discharging upon the ground, into a ditch, dry run, or ravine. In the latter case the effluent must be practically as stable as any surface water.

Broad irrigation can be substituted for any of the above methods when conditions are favorable. The selection of the proper method of treatment should be given careful consideration by a person well versed in the subject. The too common practice of adopting dilution or septic tank treatment without study of the problem cannot be recommended.

23. Inspection and Control of Sewage Disposal Plants.—All sewage disposal plants should be inspected periodically. The length of time between inspection will depend upon the character of the plant and upon the degree of purification necessary to prevent a nuisance being created in the final body of water into which the effluent is discharged. They should be inspected at

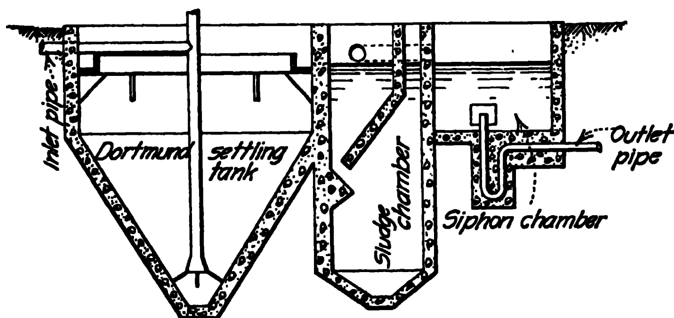


Fig. 7.

least every three months and the oftener the better Satisfactory operation may be judged by sight, smell, physical, chemical, and bacteriological tests and analyses.

Septic Tanks.—A relatively clear, light colored effluent with little or no odor at a distance of 50 ft. indicates good operation. A milky or light creamy colored effluent generally indicates that too fresh sewage is leaving the tank. This condition may be caused by the tank being too small, or by the tank being loaded with sludge and the discharge taking place by a short-cut passage through the tank, or possibly the baffles have become removed and the flow is

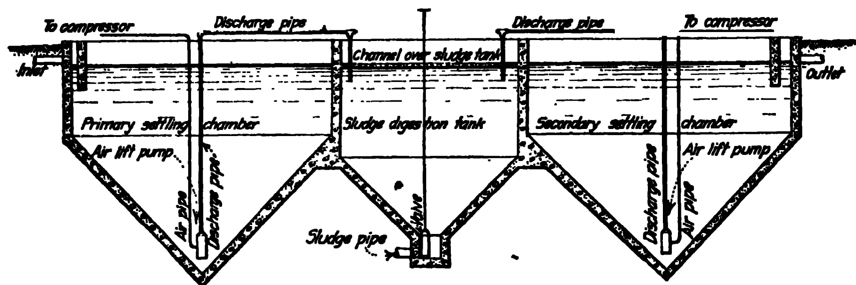


Fig. 8.

direct from the inlet to the outlet. If the effluent is dark colored and contains particles of black humus, the tank likely needs cleaning as it is either now discharging more organic matter than comes into the tank, or the flow into the tank is erratic and is unduly disturbing the sludge.

The remedies that may be applied for these defective conditions are: clean the tank; make necessary repairs, if any; reduce excessive flow into tank, if possible; make sedimentation tests and chemical and bacteriological analyses to determine actual work done by the tank. If the tank is insufficient in size, build another compartment.

At each inspection, tests with poles should be made to determine amount of sludge on the bottom of the tank and the amount of scum. See that flow takes place over full length of weirs if there are any.

Imhoff Tanks.—If sewage is extremely fresh when it enters the tank, there will be considerable scum on the tank after it has been in use a month or more. This should not be allowed to become septic, but should be removed, forced under liquid, or broken up. Violent disturbance should be avoided. If effluent is dark colored with black humus particles entrained, either the slot is closed or the settleable solids have collected on the slopes of the tank and are becoming septic. The remedy for these conditions is to squeegee the slopes, draw off the sludge, and inspect the slot with a long pole or rod. If gas vents are foaming, draw off sludge or remove any scum from the vents.

Draw off some sludge each month and keep the sludge loose in the sludge chamber by the use of water under pressure. Make sedimentation tests and chemical and bacteriological analyses, quarterly or oftener.

Filters.—Sand filters must be dried and scraped whenever there are signs of clogging to any large extent. Sprinkling filter nozzles have to be removed from time to time to keep out matches, corks, etc. When the filter shows signs of clogging, remove spray nozzle and plug opening for a while. Humus tank under filter should be cleaned out frequently.

Sub-surface filters should be inspected so far as is possible, and in some cases dug up if necessary, to determine the cause of any trouble such as odor, clogging, putrescibility, etc.

Sedimentation tests and chemical and bacteriological analyses should be made quarterly or oftener if a high degree of purification is necessary.

SECTION 4

WATERLESS TOILET CONVENIENCES

By Frank R. King

1. Outdoor Privies.

1a. Deep Vault Type.—In localities where sewers are not available, where private sewage disposal systems are not practicable, or where the water supply is derived from shallow surface wells, a sanitary privy or some other approved type of toilet is essential for the safe disposal of human wastes.

An outdoor privy should not be located at a spot such that liquids from the vault may pass either over the ground surface or through the ground. Where possible, it should be located at least 100 to 150 ft. from the nearest surface well or spring, and no water-tight privy vault should be located within 10 ft. of any cistern or within 20 ft. from any surface water supply used for drinking purposes.

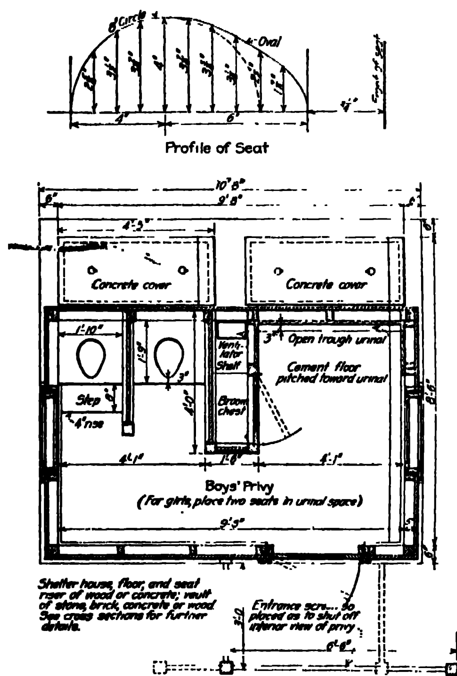


Fig. 1.—Floor plan of a school privy.

It cannot safely be said that any soil within 500 or 1000 ft. of an open vault, privy, or cesspool will protect a shallow, dug or drilled well, or spring, from pollution. Any soil full of seams, a porous rock or one full of crevices, or a very coarse gravel may allow the contents of the vault or cesspool to leach to the nearby source of shallow water supply with little or no purification.

The privy must be so designed and constructed that it can be kept reasonably clean and in a sanitary condition without too much labor. *A* broom or service closet as shown in Fig. 1 should be provided.

The vault or pit must be as dark as possible, of adequate depth, and extended with suitable material, such as concrete or masonry work, at least 8 in. above the surface of the surrounding ground, so that small animals and vermin cannot have access to the excreta, and it should be flyproof.

GENERAL INFORMATION AND SPECIFICATIONS FOR PRIVY CONSTRUCTION

Foundation.—Foundation or supports should be of durable construction, and when not a part of the vault should be extended below the frost line.

Privy Vault.—The kind of vault to be selected depends upon the following conditions:

(1) The location of the privy with relation to wells, driven points, springs, streams or other source of water supply.

(2) Capacity of vault required to serve existing conditions and to conform with the type of floor construction chosen from the sketches given.

(3) Character and stability of the soil into which the vault is to be sunk.

(4) Character of the material most suited or convenient for the construction of the vault, such as brick, cement, or tile blocks, or stone laid in mortar; concrete walls with the bottom left open to the soil or made with water-tight walls and bottom; or wood construction, as may best serve the existing conditions.

(5) Whether the vault is to be constructed for permanent service or provided with an opening for the removal of contents, or the shelter-house removed for cleaning of vault or moved to a new location.

The vault should have a minimum inside dimension of at least 2 ft. 8 in. and extend the full length of the privy. It should have a depth of from 6 to 10 ft., depending upon the character of the soil and size of vault serving the particular situation best. Vaults provided with a cover for cleaning purposes must have a width of at least 3 ft. 8 in., interior dimensions, extend the full width of the privy and be provided with an access space to the vault from 16 to 18 in. wide (Figs. 2 and 3).

For estimating or determining the capacity required for a privy vault the following information is presented:

Capacity of Vault for School Building Having an Average Attendance of 15 *Children Per Day* (For other buildings deduct or add as the case may be).—

Amount deposited per child for a 1-mo. school period, approximately 1 gal.

Total deposit per child for a 9-mo. school period, 9 gal.

Total deposit for 15 children for 9-mo. period, 135 gal.

A vault as shown in Fig. 5, 2 ft. 8 in. wide, by 4 ft. 8 in long, by 6 ft. 0. in. deep = 62 cu. ft. = 465 gal.

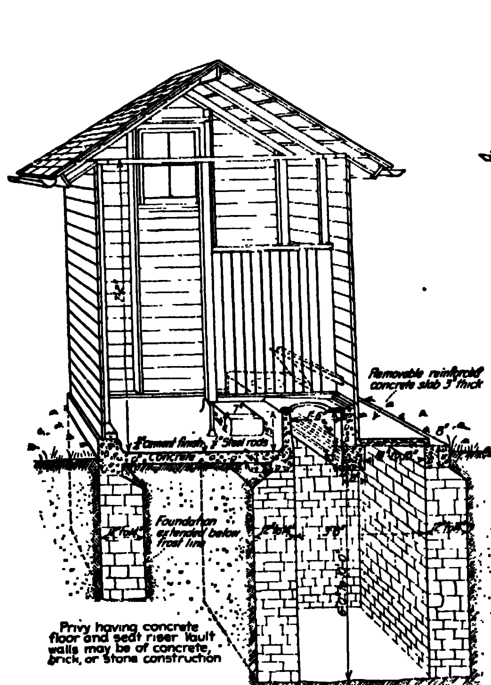


Fig. 2.—Cross section through seat, Fig. 1.

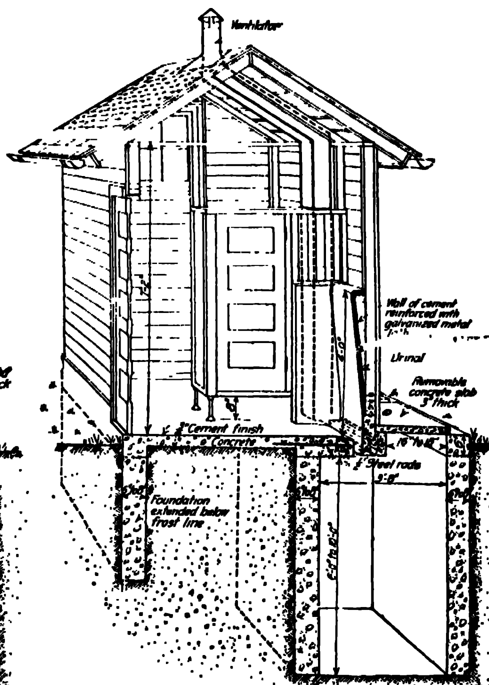


Fig. 3.—Cross section through urinal, Fig. 1.

In determining or estimating the length of time a vault will serve without cleaning, proper allowance should be made for evaporation, soil absorption, etc., of liquid contents. This depends upon the character of the soil and whether the soil is reasonably free from water. Approximately 80% of the deposits are or will turn into liquid by bacterial action and decomposition.

Accordingly, a vault of the above capacity, located and constructed to permit leaching of the liquid contents, should serve from 12 to 16 yr. without requiring cleaning out of the contents.

A vault of above dimensions and water-tight construction, allowing for natural elimination of liquids by the process of evaporation, which is enhanced by the vault ventilator, will require removal of the contents once in every 6 yr.

Vault capacities for larger privies should be estimated in accordance with the foregoing information. In most cases large vaults are preferable.

Floor Design, Materials, and Construction.—The floor should preferably be made of concrete, reinforced with steel rods where necessary (Figs. 2 and 3). The top coating should be applied as soon as possible after laying the concrete. If for any reason the top coating cannot be applied until the concrete is hard, then the surface must be thoroughly cleaned and washed with a cement grout. The top coating should be at least ¾ in. in thickness, of a dense, rich mixture, composed of one part Portland cement and two parts sharp sand free from loam, troweled and

finished to a smooth surface and properly cured. Experience has proven that in order to obtain the best results for toilet room floors, the top coating must be kept in a moist state by proper damp covering for a period from 10 to 20 days.

Floors of wood construction should conform with the following minimum requirements: Joists should be not less than 2 × 6 in. of sound material placed 16 in. center to center; end pieces and headers of same size and material; wall support extending across rear of vault composed of two 2 × 8-in. joists, constructed in accordance with cross section of privy shown. The floor should consist of 1-in. dressed, matched flooring free from knots and other defects, laid tight, in a workmanlike manner, and kept well painted and in such condition as to prevent absorption. A double thickness of flooring is recommended.

Construction of Floor and Seat Risers.—The floor, wall base, and riser in front of the seats should be made of material other than wood, which does not readily absorb moisture, such as concrete faced with cement or other smooth, non-absorbent material which can be easily cleaned (Fig. 2).

When wood is used as a substitute for concrete in the construction of floors, base, and seat riser, it should be of good quality, constructed as shown, and well protected with water-proof paint (Fig. 4).

Walls of Shelter-house.—The frame work for a privy of wood construction should consist of 2 × 4 in. studdings, dressed where exposed, and placed as indicated on the floor plan on cross sections shown.

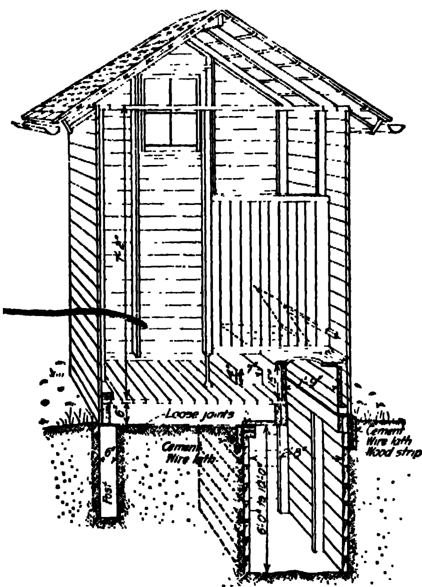


FIG. 4.—Privy having floor and vault of wood construction so designed that shelter house can be removed for the cleaning of the vault.

Interior walls should be lined with dressed flooring and exterior walls covered up with a fair grade of dressed shiplap, drop siding, or a high-grade matched flooring.

Door, windows, etc., should be well trimmed.

The whole work should be executed substantially, in a neat, workmanlike manner, with particular regard to excluding rain and snow.

Roof.—The privy shelter-house shown in sketches is to be provided with a roof of ordinary substantial wood construction, consisting of 2 × 4-in. rafters, 2 ft. on centers, roof boards and cornice, and covered with a good quality of wood shingles, or other adequate roofing material so constructed as to exclude snow and rain.

Eave Troughs.—The roof should have eave troughs of sufficient size and substantial materials, placed as indicated on the sketches, so as to shed water from the approach, door, and vault cover.

Windows.—The window glass area for a privy containing one or two seats should be at least 4 sq ft. and 2 sq. ft. additional for each additional seat. Two feet of urinal space is equivalent to one seat. These windows should be hinged at the bottom so as to swing inward, and be provided with a suitable latch lock at the top and a transom rod or short chain to control the window. Windows should be so constructed that they can be opened to give adequate ventilation and should be equipped with outside screens.

Door.—The door should be at least 1¼ in. thick, from 2 ft. 4 in. to 2 ft. 6 in. wide, and from 6 ft. 6 in. to 7 ft. high; hung with substantial hinges and provided with lock and key. A reliable self-closing device should be provided for the door, such as a spring or housed-in weight.

Partitions.—Seats should be separated by a wood partition securely anchored at bottom and top, and not less than 5 ft. 6 in., nor more than 6 ft. in height from the floor. A space of 10 to 12 in. should be left between the floor and the bottom of each partition.

Each urinal trough should be so located as to have back and ends or walls to give privacy.

Number of Seats and Urinals.—For places of employment or similar public buildings, one seat should be allowed for every 20 females, and one seat and one urinal for every 40 males. For schools, one seat for every 20 females or fraction, except for grammar and primary grades, where there should be one seat for every 15 females or fraction; and one seat and one urinal for every 40 males or fraction, except for grammar and primary grades, where there should be one seat and one urinal for every 30 males or fraction. Each 2 ft. of urinal space is considered equal to one urinal.

Seats.—The seats for each privy should be made of wood painted and varnished to make them impervious to moisture, and may be provided with tight-fitting covers.

Seat openings should be 8 × 10 in., oval in shape, and should begin 3¼ in. from the front or seat riser (Fig. 1).

Urinals.—The urinal shown in Figs. 1 and 3 should be designed and constructed of materials and in a manner to conform with the sketches. The wall, ends, and approach must be of nonabsorbent material. When made of concrete, a rich cement-finished, smooth facing, asphaltum-coated, must be provided. When made of wood, the walls, ends, and floor must be provided with a No. 24 galvanized iron (or heavier) facing, and be asphaltum coated.

To make a concrete urinal non-absorbent the following is required: A top coating ¾ in. thick, of a dense, rich

mixture, composed of one part Portland cement and two parts sharp sand, free from loam, troweled and finished to a smooth surface. Wall and ends of the urinal should be asphaltum-coated, the coating to be renewed whenever necessary. (An asphaltum coating can be applied successfully only on a perfectly dry surface.)

***Ventilation of Vault and Shelter-house.*—The space under the seats should be ventilated by a vent pipe (Fig. 3), which should have an opening 5 in. square for every square yard or major part thereof of the vault surface. This vent pipe should extend upward from the vault through and at least 3 ft. above the roof, and be constructed of wood or No. 24 galvanized sheet iron. Thus a two-seat privy should have a vent pipe 4 × 12 in. or its equivalent in size. It is recommended that this ventilator be equipped with an efficient vent hood to guard against down-drafts (An efficient ventilator is considered to be a vent terminal provided with a hood of the siphonic action type, or its equivalent in some other type which will promote the ventilation.)**

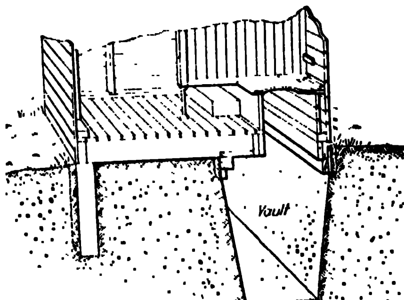


FIG. 5.—Earth pit type.

***Service or Broom Closet.*—The service closet should be substantially built of dressed lumber, well braced, and provided with floor, ceiling, door, and ample shelving. A space from 6 to 12 in. should be left between the floor and the bottom of the cabinet. The top of the cabinet should be not higher than 7 ft. above the privy floor. This closet should be equipped with broom, mop, bucket, soap, toilet paper, lime or other disinfectant, and any other materials necessary for maintaining the toilet in a sanitary condition.**

***Entrance Screen.*—The entrance to the privy should be provided with an adequate screen of wood, metal, or its equivalent, so placed as to shut off the interior view. This screen may be of wood lattice construction supported by posts and substantially anchored. A space from 6 to 12 in. should be left between the ground and the bottom of the screen. The top of the screen should be from 5½ to 6 ft. above the surface of the ground.**

***Painting of Wooden Privies.*—The exterior of privies of wood construction should be well painted, and the interior walls, partitions, and ceilings should be well covered with non-absorbent white or light gray paint.**

***Designation of Sex.*—Each privy should be distinctly marked with regard to the sex using it, and no person should be allowed to use a privy assigned to the other sex.**

1b. Earth Excavation or Pit Type.—Where the ground has sufficient stability to prevent caving in, the earth pit (Fig. 5), properly protected near the surface of the ground, may under favorable conditions successfully be substituted for the permanent type of vault. Its advantages are simplicity of construction and the easy removal of the shelter-house to a new location and pit; the disadvantages are its unsuitability in low or swampy lands, in soil not free from water or of seamy clay or rock formation, or where there is danger of polluting surrounding soil or water supplies. For other particulars consult vault requirements in the preceding article.

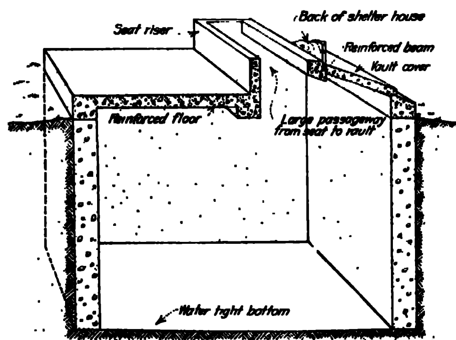


FIG. 6.—Large vault.

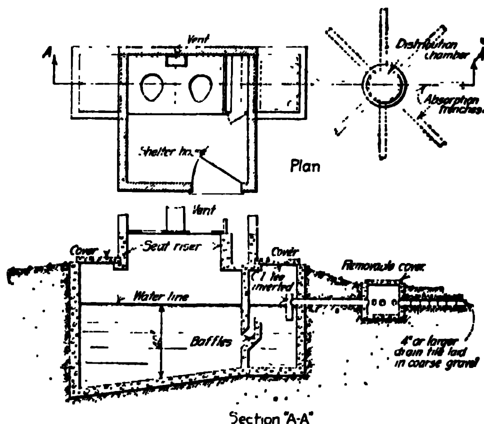


FIG. 7.—Septic privy.

1c. Water-tight Vault Type.—The design and construction of this type of privy are in every particular the same as those of the deep vault, except that the vault is of water-tight construction (Figs. 3 and 6).

The vault content of this type is in most cases found in a semi-liquid state except where each successive deposit is covered by a layer of ashes, lime, or dry earth. Contents must be removed at more frequent intervals than required with the soil absorption type. The use of this privy is now generally required wherever there is danger of contaminating a drinking water supply.

1d. Septic Privy (*Commonly known as the L. R. S. type*).—The so-called septic privy consists of a tank usually having two or more compartments of substantial water-tight construction, each of a certain required capacity. The first compartment, or receiving chamber, is situated below the seat opening. The tank is provided with one or more manholes so placed that the interior is made accessible for cleaning. Baffle walls and inverted outlets are so placed and constructed as to allow the liquids to pass over to the disposal unit (Fig. 7).

Capacity and Depth.—The size of the compartments should be based on the number of persons using the privy. The first compartment (the liquidation and sedimentation chamber) should have a minimum capacity below the water line of at least 25 gal. per person using the privy, but in no case should the liquid contents capacity of the first compartment be less than 100 gal. and the depth less than 36 in. The second compartment (liquid effluent chamber) should have a minimum capacity of 6 gal. per person, but in no case less than 50 gal.

Capacities and dimensions in accordance with the following table are considered good practice to follow:

Number of persons using privy	Capacity of first chamber below waterline (gallons)	Capacity of second comp't below waterline (gallons)	Volume depth (inches)	Distance above waterline (inches)	Combined length of absorption trenches (feet)
5	125	50	36	12	20 to 30
10	200	75	40	to	30 to 40
15	275	100	40	24	40 to 50 (Fig. 7)

Disposal of the Effluent.—Disposal of the liquid flowing from the second compartment is effected by means of soil absorption in a manner similar to the disposal of effluent from residential septic tanks, or as described in Art. 2 relating to chemical closet tank contents disposal. Owing to the comparatively small amount of liquid to be disposed of, a much less amount of drain tile or trench is required.

Operation.—It is obvious that, although by bacterial action the septic privy changes the major part of solid wastes into liquid, the liquid and solid wastes still are as dangerous to health as is the original fecal matter. Care must be exercised, therefore, in their disposal and the system operated in accordance with the principles under which the system functions, namely:

1. On the completion of the system or before it is placed in use, the vault must be filled with water (preferably rain water).

2. Water must be added at frequent and regular intervals so as to maintain an approximately fixed water level. Five or more gallons per week are usually required, depending on the size of the vault and the degree of loss by evaporation.

3. Sludge or residue must be removed from the bottom of the vault whenever it rises to exceed a depth of one-fourth of the liquid contents.

4. Heavy surface scum must be broken up at intervals and allowed to settle.

5. All material other than fecal matter, toilet paper, and water must be excluded.

6. Disinfectors, deodorizers, and other chemicals must be excluded because they retard materially bacterial action and liquidation.

In connection with public places, the foregoing maintenance principles generally must be followed. It is obvious, therefore, that this type of privy is not suitable for public or semi-public buildings.

The principal *installation factors* that require observance are:

1. Location of the privy with reference to sources of water supply.
2. Character of the soil as to effective and safe disposal of tank effluent.
3. Design and capacity.
4. Water-tight vault.
5. Effective vault ventilation.
6. Climatic conditions (protection against frost, etc.).
7. Regular and systematic maintenance.

It is claimed that this type of privy, under suitable climatic and certain other favorable conditions, has some advantages over the common type. Its satisfactory operation under all conditions has not as yet been established, nor has it been proven that it makes for a reduced cost, less care, or a safer disposal of the vault contents.

1e. Commercial Septic Privy.—Various makes of this type can be found in the market, similar in principle of operation, design, and construction to the septic privy previously described.

1f. Removable Bucket or Receptacle Type.—A privy of this design differs from the other types treated only insofar as it is equipped with a removable, water-tight bucket or larger receptacle for receiving the fecal deposits, rather than with an underground container of other vault types previously described (Fig. 8).

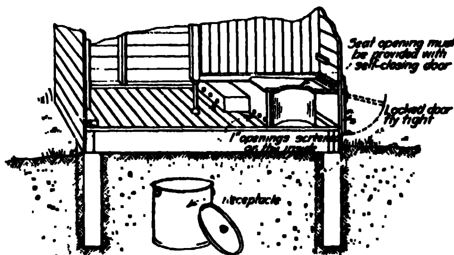


Fig. 8.—Bucket type privy.

The advantages of the removable bucket privy are: (1) It may be erected and removed quickly; (2) it involves a low initial cost; and (3) when effectively operated, it guards against pollution of the surrounding surface, soil, or water supplies.

The disadvantages are: (1) Its capacity is limited according to the size of the receptacle and the number of users, thus requiring regular and frequent attention. Generally this degree of care is not given, resulting in overflowing vaults and highly dangerous conditions. (2) Deposits are more accessible to flies and vermin than in any of the other types of privies described. (3) The deposits are more subject to sun heat than those in deep vaults, thus intensifying putrefaction and fermentation and causing offensive odors. (4) In cold climates the bucket contents are subject to frost, making satisfactory removal more difficult.

Important requirements relating to design, construction, use, and maintenance include the following:

1. It is highly essential that the enclosure or box housing the deposit containers, bucket, or other receptacle be made fly-proof, and built so that the containers can readily be removed and replaced.
2. That this privy have two or more seats, each provided with a receptacle.
3. That the receptacles and housing enclosure be so designed that all parts can be maintained in a sanitary condition with a minimum amount of effort.
4. That the seat covers be self-closing and the openings properly designed and constructed with relation to the location of the bucket, pail, or larger receptacle used.
5. That the receptacles be of proper design, kind, weight and quality and of water-tight construction.
6. That the receptacles must be so located and fitted below the seat openings that they will receive all the deposits without spattering upon adjacent surfaces.
7. That satisfactory means for regular disposal of the deposits be provided.
8. This type of privy, being affected by climatic conditions (heat and cold), it is essential that during warm weather each successive deposit of fecal matter be covered with a layer of dry earth in order to absorb moisture and reduce odors.
9. That the privy entrance door be self-closing.
10. Wherever practical, the rear of the privy should face the north or northwest in order to avoid the rays of the sun.

11. That effective ventilation be provided by means of a vent pipe extending from the bucket enclosure to a point above the shelter-house.

This type of privy usually proves unsatisfactory in respect to service and comfort in that it requires more care than the average individual is disposed to bestow upon it. If it is to render a reasonable degree of adequate service and prove safe for the public, it must be under the direct supervision of a highly developed, effective, community scavenger service system.

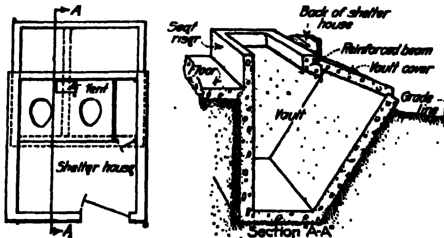


Fig. 9.—Shallow vault type privy.

1g. Double Compartment, Alternating Use, Shallow, Water-tight Vault Type.—This type of privy must always have two or more seats, each provided with a separate vault of sufficient capacity to allow for a six months' or longer rest period for the vault deposits, which is accomplished by alternating use. The fecal deposits are thus seasoned, making the final disposal of the residue less dangerous and objectionable. The alternating method of use to promote the seasoning of the vault contents still is in the experimental stage. Experience with park, fair-grounds, and similar vaults unused for a considerable time (often six months or longer), has demonstrated, through the rest period thus gained, that the objectionable odors usually prevailing in and around the vaults can be to a large extent eliminated.

This type of privy should be operated as a dry vault, which can be done by covering each deposit with dry earth, lime, or ash, or a mixture of either of these, or it may be operated as any other common vault. It should be understood, however, that the vault has a limited capacity, and that its contents in either case must therefore be removed more often than is necessary with larger vaults.

Operation Precautions.—Nothing but fecal deposits, toilet paper, or earth, lime, or ashes used for covering deposits should be allowed to enter the vault, and an adequate quantity of this material should be used to maintain the vault in a semi-dry state. Before the vault has been used, and after its cleaning, a layer of horse manure 2 in. thick should be placed on the bottom of the vault, and this followed by a layer of dry earth mixed with lime to a depth of 2 in. This will aid materially in the decomposition of the contents. The resting compartment must not be used during the seasoning period, and effective vault ventilation must be maintained.

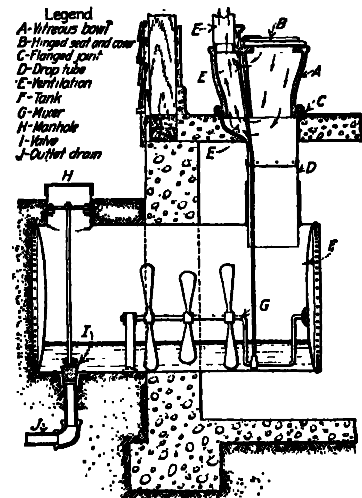


Fig. 10.—Cross section of chemical closet.

2. Chemical Closets (*Type: Bowl and Tank*).—A chemical closet system consists of a vitreous china, trapless bowl, equipped with a hinged seat and cover, similar in design and dimensions to the railroad coach bowl. It differs from the modern water-flushed bowl in its design, is larger, and lacks the water-sealed foul-air-excluding trap.

Deposits in the bowl are conveyed through an untrapped metal tube or pipe to an iron tank and retained in a strong chemical solution for sterilization and deodorization. Removing of offensive odors emanating from the tank, bowl, and room is made effective by extending from these units a vent pipe of metal construction within the building and through and brought above the highest point of the roof.

Liquefaction and sterilization[1] of fecal matter and its deodorization are accomplished to a marked degree by the action of the caustic soda solution with which the tank is charged to about one-fifth of its capacity. Removal and recharging of the tank contents are required about every 6 mo. (Fig. 10).

Chemical closets, frequently defined as "waterless toilets," are still in the advanced stages of successful development. The degree of satisfactory service this type of closet will render depends, obviously, upon the specific conditions existing, as well as upon the type or make of the system, the proper manner of installation, its use by the individual, and the care given it. Like other types of waterless conveniences, chemical closets do not afford supplementary sanitary aids, such as running drinking water, bathing or washing facilities, and to this extent, where other conditions are equal, they are deficient when compared with water-flushed toilets, so far as they contribute to personal convenience, comfort, hygiene, and general sanitation.

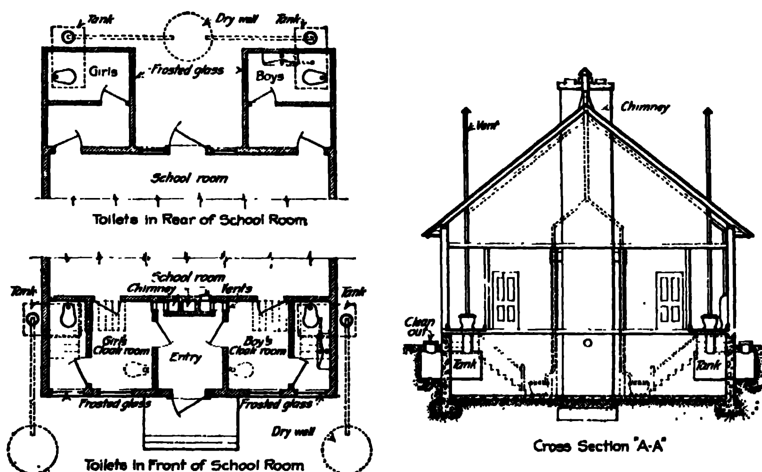


Fig. 11.—Chemical closet installation.

In localities where public water supply or sewerage systems are not available, or where an efficient private water supply system of the "compressed air storage" or "air pressure delivery" type or its equivalent cannot reasonably be provided and maintained, or where the lay of the land and character of the soil are such that the effluent from a sewage treatment tank cannot successfully be disposed of by one of the variously known methods, a chemical closet conforming with the minimum requirements outlined in this chapter will, under certain favorable conditions, give a degree of satisfaction.

The majority of states and smaller municipalities have no regulations prohibiting use of the chemical closet except where public sewer and water services are available. A few states grant permission to install such closets under permits, subject to rules and regulations. Character of the premises, kind of building, purpose for which it is to be used, type of system and method of installation are all taken into consideration in passing upon the approval of the installation. In granting permission the state or local governing body usually makes it plain in the permit that it does not assume responsibility for the satisfactory operation of the installation in whole or in part, and that it reserves the right to order the removal of the system should conditions dangerous to health arise through its use.

In order to insure a proper degree of comfort, safety, and sanitation, the installation should conform in every respect with the federal, state, and local requirements relating to (1) number

[1] Purification through the destruction of bacteria and other disease-producing organisms takes place in accordance with the degree of the phenol coefficient of the chemical solution, which is subject to deterioration resulting from fecal and urinal deposits.

and kind of fixtures, (2) "housing" design of enclosure, (3) standards of construction, (4) kind of materials for floor, walls, and partitions, (5) effective room ventilation through exterior windows and vent flues (as the case may require), (6) adequate light, (7) proper location with regard to convenience and privacy, and (8) its maintenance, as demanded by the special make of closet and appliances to be adopted (Fig. 11). In the main these essential requirements conform with those for water-flushed toilets.

The materials entering into the various units comprising the system, must be of proper design and durable construction, and so installed and maintained that the highest possible degree of efficiency is insured.



FIG. 12.—Bowl and vertical tank type for small homes and summer cottages.

Tank.—The tank should be cylindrical or oval in form and be made of durable, best-grade iron or steel, not less than No. 14 gage, thoroughly coated on the outside with asphaltum, applied hot, or with other approved compounds. The exterior of the tank where not exposed should further be protected by two or more coats of burlap, each laid in hot asphaltum or some other efficient waterproof covering.

It is considered good practice to require that the operating capacity of the tank for a single-bowl installation for ordinary use be from 125 to 150 gal. and increased in the ratio of 100: 125 gal. for each additional bowl. For school building use, the tank capacity should not be less than 10 gal. per pupil based on a 9-mo. school period.

The operating capacity of the tank shall, in all cases, be based upon the seating capacity of the school, and no such tank shall have a capacity of less than 10 gal. per pupil. One tank of 200 gal. capacity shall be installed for every 20 females or fraction, and one tank of like capacity for every 20 males or fraction. All such tanks shall be increased [in the ratio of 10 gal. for each additional 15 sq. ft. of classroom floor area], equivalent to a ratio of 200 gal. for each additional 20 females or males or fraction, tributary reto, in accordance with the following table:

TANK CAPACITIES

School seating capacity	Floor area of classroom, square feet	Number of tanks	Minimum capacity of each tank, gallons
40	600	2	200
80	1200	2	400
120	1800	2	600
24	360	2	120
30	450	2	150

Exception: Existing schools actually having a capacity of less than 40 pupils may install smaller-capacity tanks, but no such smaller tanks shall have a capacity of less than 125 gal., or less than 10 gal. per pupil, tributary (based upon the seating capacity of the school in accordance with the above table); and no such tank shall be equipped with more than one bowl for females and one bowl for males, and all such tanks shall be so installed that they can conveniently be drained of their contents and re-charged.

NOTE.—The above requirements are based upon the following:

1. That the attendance of the different sexes be equally divided.
2. That a 9-mo. school period be maintained.
3. That the school may be used for community or civic meetings, etc.
4. That deposits per child and other liquids, such as chemical and bowl washings tributary to the tank, shall equal not more than 10 gal. per child for the period stated in item 2.

NOTE.—It is recommended that there be one bowl and one urinal for each 15 males and two bowls for each 15 females.

Occupational use of the building and facilities for successful removal of tank contents and the care of the system are factors that must be taken into consideration.

It is important to have openings properly spaced with relation to all fixtures tributary and that joints and connections subject to liquid action be made properly by means of riveting or welding, or in other approved manner.

Drop Tube.—The connecting or drop tube between the bowl and tank must be free from offsets. It is recommended that it be 11 or 12 in. in diameter and not more than 4 ft. long (shorter where practicable), and that it be made of substantial and durable materials capable of withstanding the eroding effects of urine. Materials with this qualification include copper, lead, brass, cast iron enameled on the inside, or some other non-absorbent, smooth finished and indestructable material.

All waste carrying tank inlets should extend into the tank from 1 to 2 in. so as to convey urine directly to the chemical solution or the tank's liquid contents.

Ventilation.—The ventilating system should be so designed that it will prove effective under specific conditions. For a single fixture a pipe of 4-in. dimension or larger (and correspondingly large for additional fixtures), free from horizontal changes in direction, usually is extended within the building to the nearest high point of the building, carried through the roof two or more feet, and the vent terminal surmounted with an effective vent hood of the siphonic action type. Or if desired, forced ventilation by means of motive power or heater may be adopted.

The material and joints used for ventilating devices should be substantial and of a quality capable of withstanding the action of moisture and gases emanating from the fixtures and tank.

Certain basic factors in connection with the system are such that it is essential at all times to maintain ventilation through the closet bowl in addition to satisfactory ventilation of the intervening room, sometimes termed the "buffer" room.

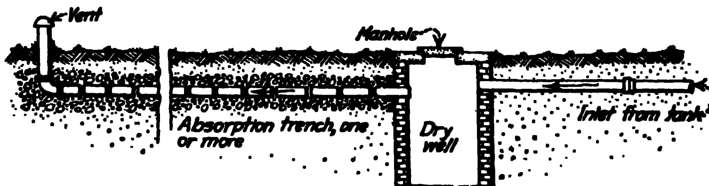


FIG. 13.—A disposal medium for the tank contents of a chemical closet.

Agitator.—The agitator, or tank contents mixer, must be of proper design and substantially constructed, and so located, designed, and installed that it may at all times be conveniently and effectively operated.

Joints.—Joints between the bowl and drop tube and between the tank and drop tube, and all other joints, should be made in a durable manner, air- and water-tight.

Valve and Drain.—The tank should be provided with an accessible water-tight valve controlling the outlet drain. Unexposed tanks should be equipped with suitable valves placed within the tank directly beneath the cleanout opening. In no case should the drain and valve opening be less than 3 in., and unexposed drain less than 4 in., inside diameter. Drain valves placed outside the tank should be of a size equal to the inside diameter of the drain outlet. The drain should be attached to the tank by a flange properly riveted or welded to it, tapped and threaded for 4-in. screw pipe.

Protection from Frost.—The system must be so installed that any part affected may amply be protected against frost.

Disposal of Contents.—With certain limitations the disposal of tank contents may be accomplished through one of the following methods;

1. Pumping or dipping and hauling away, a process proven by experience in most instances to be impracticable and unsatisfactory from the standpoint of service and sanitation, except under certain very favorable conditions in the private home.

2. By discharging into a dry well or leaching basin (Fig. 13) consisting of an underground chamber or well provided with a manhole and cover, walled up with material allowing the liquids to percolate through it, such as dry rubble or brick work. The capacity should be at least 2 to 5 times that of the tank contents volume. The lower limit is to be taken for clay or compact soil and the upper limit for sand, gravel, or equal soil, or by means of a combination trench and dry well. The more important requirements which must be taken into account are the lay of the land, character of the soil, amount of liquid, character of waste to be disposed of, location with respect to wells or other water supply sources, and grade (not less than ½ in. per ft.) of the drain from the tank to the basin.

Accessibility.—The cleanout opening of the tank should be so located, and where practicable the tank so encased, that access to it for inspection purposes may be readily possible. When the cleanout is placed outside the building, it should have a concrete manhole and over.

Tank cleanouts should not be placed within the building when it is proposed to remove the tank contents by pumping or dipping.

Chemical.—The phenol coefficient of the chemical used should be clearly stated on the package or container of the manufacturer, and the chemical should be a dry caustic of standard commercial quality with a phenol coefficient of at least 15. The charge per bowl or urinal is from 20 to 30 lb., dissolved in water according to the manufacturer's instructions. The chemical solution thus used must be maintained at all times of such strength as to sterilize effectively the contents of the tank.

Care of the System.—It is extremely important in securing serviceability and sanitary efficiency that the installation be maintained clean and in good repair. It should be operated in accordance with the manufacturer's instructions and state or local regulations.

Guarantee.—The engineer, architect, installer, or owner should require the manufacturer to give a bona fide guarantee governing all parts of the system and its successful operation, as set forth by the manufacturer and in the terms of agreement and contract.

The data given in the foregoing paragraphs are intended to serve as a guide for installations to be placed within or in connection with buildings serving for human habitation. Certain minor modifications as to building structural features may perhaps, in some cases, be permissible where the system is housed in a detached outdoor building. It is extremely important, however, that all such installations be carefully planned, specified, and installed.

3. Portable Chemical Closets.—The portable type of chemical closet consists of a cabinet constructed of wood or metal, equipped with a removable metal can or bucket, and charged with a caustic chemical solution (soda dissolved in water) in the ratio of approximately 1 pt. of chemical to 3 or 4 pt. of water.

Disposal of the bucket or can contents must receive attention at regular, frequent intervals, and must be accomplished in such a manner as not to create a nuisance or other objectionable conditions.

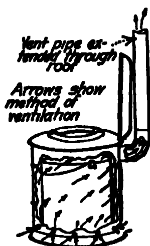


Fig. 14.—Portable chemical closet.

Ventilation of the cabinet, bucket, and room is sought by extending a vent pipe from the cabinet through, and to a point above, the roof (Fig. 14).

There are numerous makes of these portable closets offered to the trade, each with attractive names and promising inducements. Experience and trial installations have repeatedly demonstrated, however, that this type of chemical closet is, in the large majority of cases entirely unfit for public or semi-public building use. If the portable chemical closet fills a need, it must be found in the home, where the service it will render depends on the manner of installation and the regular care that it is likely the individual user will give to keep it in a proper sanitary condition. If permitted at all, its use therefore should be restricted to the private home or places where the same degree of intensive care is devoted to its maintenance.

The Chem-o-let type shown in Fig. 12 is of more recent design, supplements the portable type, and is capable of rendering satisfactory service for small homes and summer-cottage use. It is proving a factor in replacing the common and objectionable outhouse.

4. Dry Closets (*Type: Heated Air Circulation and Burning Out of Vault Contents*).—The dry closet system as now designed, constructed, and operated may be defined as a sanitary appliance of questionable merit. It consists of a vault equipped with toilet seats, urinal, air ducts, dampers, heaters, etc., and is intended to dispose of urine and excreta by means of warm or heated air and periodical burning out of the remaining dry fecal matter. The satisfactory functioning of the system is subject to numerous conditions, including design, construction, materials, occupational use of the building, and the necessity of constant care in its operation.

Seat and Hopper.—These comprise a hinged self-closing seat fitted to an iron hopper of special design and construction, attached to a cast-iron plate mounted over a water-tight vault or duct (Figs. 17 and 18).

Urinal.—This consists of a stall rising from the floor, constructed of glass, slate, iron, or equally suitable and substantial non-absorbent material. The bottom of the stall has an open trough or gutter leading directly to the vault or into a ventilated water-tight duct terminating in the drying vault (Fig. 19). The floor of the toilet room should slope from all points toward and into the urinal trough.

Deposits.—The urine or fecal deposits made in the bowl or urinal are retained in the vault, the liquids evaporated, and dried solid matter disposed of by cremation, or "burning out" (Fig. 17).

Vault.—The vault is of water-tight construction, square or oval in form, 3 to 4 ft. in width, 4 to 5 ft. in depth, and of a length as may be required but not to exceed five seats in a run, and is equipped with drying decks and air passages (Figs. 18 and 19).

Disposal of Vault Contents.—The capacity of the vault or duct below the seats is such that the accumulating excreta must be removed at regular intervals. This is accomplished (1) by placing a small amount of wood directly below the seat opening (Fig. 17) before the system is put into use and operating it so as to dry thoroughly the vault contents; (2) by firing the stack heater so as to produce an effective draft (Figs. 15, 16, and 17), and saturating the dried excreta deposits with kerosene oil, starting the burning out fire at the seat opening nearest to the foul air stack, and adjusting air intakes, dampers, etc., as the process may require; and (3) by removing and disposing of the residue in a proper manner and placing the system in good repair and effective operating condition.

Stack or Vault Heaters.—The system functions by means of air circulation, and is therefore dependent upon a large volume of warm air having a constant flow through the vault. To accomplish this a vent flue or stack of brick or equivalent construction is placed at the end of the "run" or vault, in the base of which an adequate fire

must be kept at all times while a deposit remains in the vault (Fig. 17). When air is taken from outside the building or where the foul air from the building is used and is not sufficiently heated, a vault heater is placed in the inlet end of the vault in which a fire is maintained for the purpose of heating the air to a degree necessary to dry the vault contents and effectively ventilate without interruption through the stack, vault, seat, urinal, and toilet room (Fig. 17).

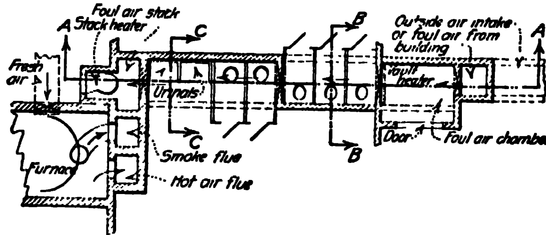


Fig. 15.—Typical floor plan of dry closet system.

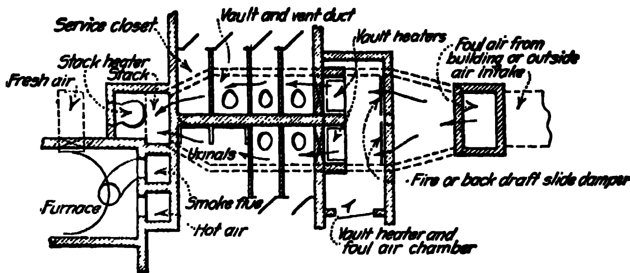


Fig. 16.—Alternative floor plan of dry closet system.

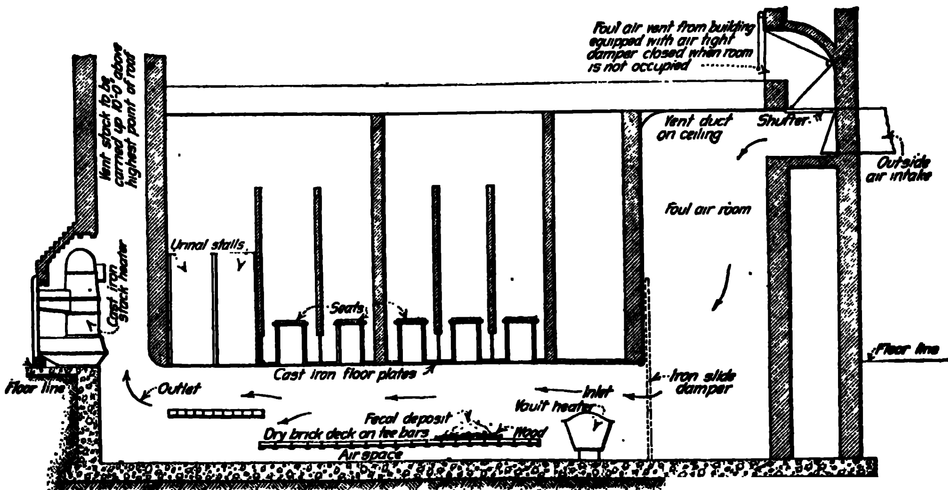


Fig. 17.—Section "A-A," Fig. 15.

Location of System.—Toilet conveniences and appliances in connection with this type of system must in nearly all cases be installed in the basement of the building (for arrangement consult Figs. 15 and 16).

Alternative Installation Details.—An adequate exhaust fan may be used as an assistant to the stack heater. If used without the heater it must be in two-unit form so that one can be kept in constant operation. When vault-drying air is taken from the outside, vault heaters must in all cases be used (Figs. 15 and 16). When air is taken

from the building dampers or shutters must be used to prevent back flow when the building is not occupied or in cases when fire in the heaters is not sufficient to maintain effective ventilation.

Where the room is of sufficient height, the horizontal inlet duct or flue may be placed above the basement floor. Where the basement is subject to water above or below the floor line, underground air ducts must be of water-tight construction and the vault placed at a sufficient height above the floor and be so built as to exclude water from the ducts or vault. In order to dispose of the unevaporated liquids, the bottom of the vault may be sloped toward a suitable point and carried by an adequate drain to a dry well or gravel absorption trench.

The engineer, architect, designer of the building, installer, or owner, as the case may be, should provide:

1. That the installations conform with federal, state, and local requirement relating to "housing," sanitation, and maintenance

2. That the materials and construction of the various units comprising the dry closet system be of proper design and so installed that the highest degree of efficiency possible is insured.

3. That the vault and conveyors be of proper design and water-tight construction.

4 That the cross section vault area below the seat hopper be of adequate capacity, at least 30 % larger than the combined foul air conveying flues connected therewith, and that the open space below the grates be at least 8 to 10 in. in height.

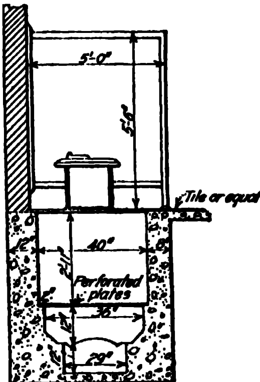


FIG. 18.—Cross section "*B–B*", Fig. 15.

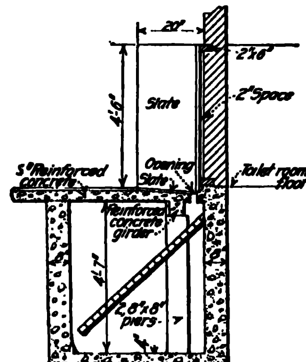


FIG. 19.—Cross section "*C–C*", Fig. 15.

5. That the foul air duct, stack, vault, and heater, or heaters, be of adequate capacity and that a fire be maintained either in the stack, or vault heaters, or heating system at all times when required, so as to insure proper ventilation.

6. That the foul air duct, or ducts, be provided with a damper of efficient design and conveniently located, and that the foul air removal system be so constructed as to exclude, under all proper conditions involving maintenance, obnoxious odors from any part of the building and so that it will comply with all established fire protection requirements.

7. That the duct or flue containing the stack heater be extended to a height from 8 to 10 ft above the highest part of the building so as to insure effective ventilation.

8. The seat hopper shall be so designed and of such material that it can be kept clean and be provided with an approved seat.

9. That the urinal be made of non-absorbent materials such as glass, slate, or iron enameled.

10. That the vault be burned out and cleaned and disinfected twice each year and oftener if necessary.

11. That the installation at all times shall be maintained in a sanitary and serviceable condition, and the material, when removed from the vault, be disposed of in such a manner that a nuisance is not created.

5. Incinerator Closets (*Army, Portable, and Stationary*).—The portable type consists of a tank mounted on wheels or otherwise made portable, one end provided with doors and the other with a smokestack. The interior of the tank is equipped with a deposit-receiving platform, fire grate, and ash pit. Seats are mounted on the exterior of the tank.

The stationary type is similarly designed, constructed, operated, and maintained.

The market offers various commercial types similar in principle.

The practical utility of all closets coming under the scope of this heading is limited to certain specific conditions, and when located properly in the open can be operated with a marked degree of safety.

SECTION 5

PLUMBING AND DRAINAGE

By S. E. Dibble and Frank R. King

PLUMBING AND DRAINAGE—GENERAL INFORMATION[1]

By S. E. Dibble

1. Main and Building Sewers.—The main sewer is that part of the sewerage system which collects the sewage from the municipality or from a number of buildings and carries it away to the disposal plant or terminal. The main sewer generally runs through the streets or alleys at a depth of 9 to 12 ft.; it may, however, lie at a lesser or greater depth. There are branches and junctions placed for the accommodation of building sewers on either side of the street at intervals depending on the width of the lots, etc. The exact location of the outlets may be ascertained from the plans filed in the office of the Department of Sewers or city engineer, as the case may be. For specific details pertaining to installation, see ordinance provision in the chapter following.

2. Subsoil and Trench Drains.—Surface water percolates through the surface earth and saturates the subsoil. Unless taken care of and carried away from the site of the building, this water will find its way into the building through the foundation walls and floors. To avoid this it is good practice to install a subsoil drain all around the building at the level of the foundation footings. Joints of tile pipe used for subsoil pipe should be left open to allow the water to find its way into the bore of the pipe and thus be carried away from site. The refill above the subsoil pipe should be broken stone within 18 in. of grade. Six inches of straw should be placed on top of broken stone and then loam to the grade. With this refill, water can easily find its way into the subsoil pipe. A piece of tarred paper laid over each joint in the tile pipe will keep out any sand that might otherwise be carried into the bore of pipe and cause a stoppage (Fig. 1). The subsoil pipe may discharge into a special trap or pit made of brick or concrete which should be connected with the sewer. The subsoil water under the building can be collected in a pit by a series of pipes laid under the house drain level and pitched toward the pit, from which it can be pumped out into the house drain by automatic cellar drainers or by electrically controlled pump. The quantity of water to be pumped determines the size of the outfit. (Consult also ordinance requirements.) The essential points in the installation of subsoil pipes are: (1) Correct depth, (2) pitch, (3) pipe and joints, and (4) refill.

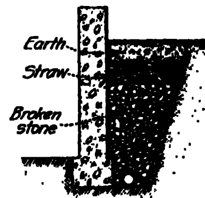


Fig. 1.—Subsoil drain.

3. Storm Water Disposal.—It is absolutely necessary that all storm waters that descend or flow upon the building or site be disposed of through proper channels. All storm water can be collected and carried off by means of roof drains, area drains, yard drains, or catch basins. Roof drains should be placed not more than 60 ft. apart, and the size should be in accordance with the following table. It is considered better to have a number of small roof drains (4 or 5-in.) than one large drain.

Diameter of pipe	Square feet of surface to be drained
4-in.	2,500
5-in.	4,500
6-in.	7,500
8-in.	13,600
10-in.	20,000

[1] For typical regulations and suggestions, see chapter following, beginning on p. 1324.

4. Roof Terminals of Rain Water Leaders.—The connection of the roof gutter with the roof drain, if on the outside of the building, should be a slip joint—that is, the tube which is

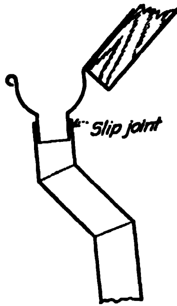


Fig. 2.—Sheet-iron pipe with gutter.

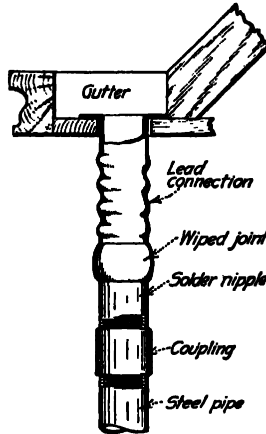


Fig. 3.—Storm down-pipe connection, steel pipe to roof gutter.

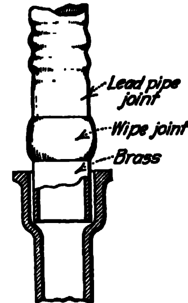
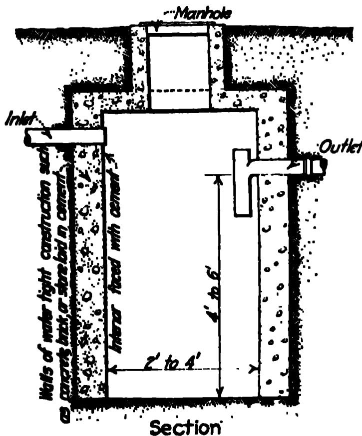


Fig. 4.—Cast-iron pipe connection with roof gutter.

connected to the gutter with a soldered joint should extend at least 7 or 8 in. into the roof drain. The material of the roof drain pipe when placed on the outside of the building may be galvanized iron or copper of round, square, or special shape, to correspond with the style of building. When the roof drain is located on the outside of the building and on any kind of passageway, the pipe material should be of cast or wrought iron for a distance of at least 5 ft. above the ground (Figs. 2, 3, and 4).

When the roof drain is placed inside of the building, the roof joint connection may be made tight by using a flexible joint to allow for shrinkage or settling of the building or pipe. The material of pipe when placed inside of the building should be cast iron, wrought iron, or steel galvanized. If cast iron is used, the roof joint connection is made by using a piece of 8-lb. sheet lead pipe wiped onto a heavy brass ferrule which can be calked into the hub of the cast-iron pipe. The lead pipe end can be soldered upon the roof gutter material. The essential points for the installation of roof drains inside or outside of building are: (1) size of drain, (2) material of pipe, (3) connection with roof gutter, and (4) supporting pipe.



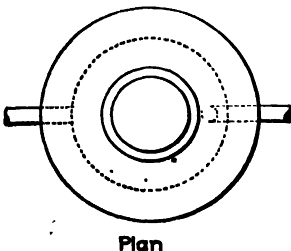


Fig. 5.—Catch basin.

5. Yard Drain and Catch Basin.—The yard drains gather surface water and should be so constructed that they will not become easily stopped by sand and rubbish entering the basin and plugging the outlet. The size of the drain depends upon the number of square feet of surface to be drained. In estimating this surface, accounting should be made of adjoining property and land that will shed its water into the drain. A catch basin similar to that shown in Fig. 5 makes an ideal one for heavy use, also for a site where springs abound, and a light catch basin might be shifted around when the ground is full of water or frost.

Catch basins can be built of brick or concrete well cemented together and plastered on the inside surface. Heavy cast-iron cesspool drains are sometimes used, but they have the objection of being too small insofar as their water chamber is concerned, and frequently becoming stopped up.

6. Area Drains.—At their best, area drains are frequently foul parts of the plumbing system. It is customary to install a drain in every area way, and often no provision is made for cleaning out the area way with running water. Facilities for flushing with a hose should, therefore, be provided. When subject to frost, the drains for area ways should have a deep seal trap placed within the walls of the building. Unless the seal is deep it will be broken by evaporation. The bottom of the area way should be cemented and pitch toward the drain.

7. House Drain.—The house drain is that part of the sewerage system which connects the house sewer with the various branches that extend up through the building. It is generally located beneath the basement floor and has cleanouts extending flush or slightly above the floor level. Cleanouts should be placed at least every 30 ft. on straight runs and at every bend or change in direction of run of the pipe. When the basement floor is below the main sewer in the street, the house drain may be extended along the basement wall or suspended from the ceiling. Head room must be reckoned with when hanging pipe from the ceiling, and at the highest point the pipe may be near the ceiling, and at the lowest point, a distance, according to the developed length, figured at a grade of not less than ¼ in. per ft.

The size of the house drain where the main sewer is of the combination type depends upon the number of water outlets discharging into fixtures, type of fixtures and apertures, number of people in the building, and number of square feet to be drained of storm water. Generally, if the size is figured according to the storm water surface the pipe size will be ample to carry the discharge from the plumbing fixtures in the building. The pitch of the house drain should be ¼ in. to the foot. The material of which the pipe used in the house drain is made should be extra heavy cast iron, tar coated. Wrought iron or steel pipe, galvanized, can be used when the house drain is above the ground. Without doubt, cast-iron pipe is the best when used underground.

The layout of a building is often the reason for plumbing fixtures being located below the main sewer level. It becomes necessary under conditions of that kind to install a sump or tank, to which is connected a pump designed to raise sewage out of the sump into the main sewer. The sump and pump are connected with automatic control, which at a given level of sewage in the sump operates and starts the pump, also stopping the pump at the low level.

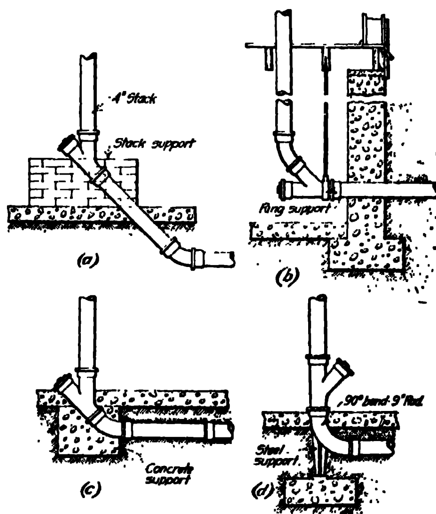


Fig. 6.

8. Waste Discharge Based on Water Consumption.—In the 50 largest cities in the United States, the per capita consumption of water ranges from 75 to 300 gal. per day.[1] The consumption per capita in a large hotel is about 100 gal. per day. The usage of this amount of water is spread over the entire day. The greatest amount will be used the first hour in the morning. About 50% of the total amount consumed will be used at this time. This 50 gal. is used as follows: Water-closet, 8 gal.; culinary department, 6 gal.; bathing, 32 gal.; washing equipment, 4 gal.

Knowing the maximum amount of water that will be used in any one hour of the day, the pipe size is figured by allowing 1 sq. in. in sectional area of the drain for each 2 cu. ft., or 15 U. S. gal. of sewage to be removed per minute.

The pipe should be large enough to carry away rapidly all solids, and yet small enough to be self-scouring; that is, the discharge should fill the bore of the pipe so that all surfaces of the bore will be flushed as the discharge passes through. The soil pipe should be securely fastened to the floors and walls. At the bottom of all soil stacks a cleanout should be placed. The stack should be supported at the bottom as indicated in Fig. 6.

Waste pipes should be installed that if occasion demands, they can be cleaned out their entire length.

9. Lead Waste Pipe.—Weights and sizes of lead pipe are shown in table. The eastern states refer to lead pipe as "E," "D," "C," "B," "A," "AA," "AAA," while the western

[1] See also chapter on "Water Consumption" in Sect. 2.

states refer to lead pipe as "Aqueduct," "Extra Light," "Light," "Medium," "Strong," "Extra Strong," and "Extra Extra Strong."

TABLE OF LEAD PIPE

Size (in.)	E		D		C		B		A		AA		AAA	
	Aqueduct		Ex. light		Light		Medium		Strong		Ex. strong		Ex. Ex. strong	
	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.	lb.	oz.
3/8	..	8	..	..	11	12	1	..	1	8	2	..	2	10
1/2	..	10	..	12	1	..	1	4	1	12	2	8	3	..
5/8	..	12	1	4	1	12	2	..	2	8	3	..	3	8
3/4	1	..	1	8	2	..	2	4	3	..	3	8	4	..
7/8	1	8	2	..	2	8	3	..	3	8	..	..	..	..
1	1	8	2	..	2	8	3	4	4	..	4	12	5	8
1¼	2	..	2	8	3	..	3	12	4	12	6	..	6	12
1½	3	..	3	8	4	..	5	..	6	..	7	8	9	..
2	3	..	4	..	5	..	7	..	8	..	9	..	10	8
2½	4	..	..	..	6	..	8	..	11	..	14	..	17	..
3	4	..	4	12	6	3	9	..	12	..	16	..	20	..
3½	..	..	5	..	..	..	..	..	15	..	18	..	..	..
4	5	..	6	..	8	..	10	..	16	..	22	..	25	..

4-in. cast-iron pipe occupies a space of 4½ in. and a fitting 6 in.; therefore, a 4-in. partition would not accommodate this kind of pipe. When cast-iron pipe is used for a waste pipe, the connection between pipe and fixture is made by means of a wiped joint, using lead pipe and a brass ferrule. The life of cast-iron pipe is found to be longer than the buildings themselves and, therefore, it makes an ideal pipe for waste lines.

Tile pipe is not used often as a waste pipe except in some cases as a drain pipe for chemicals, and when so used it should have built around it a casing of reinforced concrete.

10. Vents.—One of the prime reasons for vents on a system of plumbing is to allow the water discharged into the pipes to run by gravity through the system of pipes until the main sewer is reached and to provide a free circulation of air throughout the system. There are various methods of accomplishing this, and the designer of the system should acquaint himself with state and local regulations governing in the locality where the building is to be constructed. Sketches show approved methods of venting (also see ordinance requirements in the chapter following). Unless vent pipes are installed with a system of plumbing, the conditions become vile, and the entire building polluted with sewer gas and drain air. The effect of this foul air upon the human body cannot be discussed here, but leaving the physical effect entirely out of the question, it is inconceivable that in this age anyone would ask another to live or work in a building polluted with such foul odors or gases. A vent pipe is as important as a waste pipe.

11. Traps.—A trap is a vessel holding a body of water and so arranged on the waste pipe that sewer gas and drain air are prevented from entering the building through fixture waste. A trap has two resisting elements: (1) the amount of water in the trap; and (2) the depth of seal in the trap. It is the seal of a trap that makes it valuable. Unless proper venting is carried out, the seal of the trap can and will be broken by syphonic action or momentum. A deep seal guards these two points. The constant current of air passing through the vent pipe and waste pipes causes the water in the trap to evaporate. The amount of water in the trap guards this point.

The traps on the market today are made in various shapes and of different metals The value of a trap may be determined by comparing it with the following features which all sanitary traps should possess: (1) interior walls perfectly smooth, (2) maximum seal to resist syphonic action, (3) all parts exposed, no interior weirs, (4) cleanouts, (5) self-cleansing, (6) joints and unions.

Traps are placed in three distinct positions:

Trap connected directly underneath fixture	Lavatories Bath tubs Kitchen sinks Trays
Trap cast in fixture........................	Water-closets Slop sinks Urinals
Trap set flush with floor or underneath flo	Floor drains Shower stalls Urinals Storm drains Area drains

In an unoccupied building the water is often drawn off to prevent freezing, and when for this reason the water is taken from traps, the latter should be refilled with kerosene which will not freeze and will seal the trap.

Non-syphoning Traps.—Years of experimenting have brought into use traps which resist, under favorable conditions, the action of syphonage. To these traps the name "non-syphoning traps" has been applied. A large variety of these traps is in use and under the present demands upon plumbing, may fill an actual need. A fixture set in the middle of the room offers no practical opportunity for the extension of a vent pipe to the ventilation pipe. Therefore, in some instances a non-syphoning trap may be used. The methods of manufacture for these traps are numerous. They perform, with certain important limitations, the function for which they are designed, yet the devices employed offer an excellent obstruction for the free passage of waste water. In time, therefore, the use of these traps becomes inoperative. Any trap with an inside weir or partition or with a mechanical device to form the seal is today considered unsanitary.

Grease traps are a distinct type of trap. The function of a grease trap is to harden all grease which is discharged from the fixture connected to it before being discharged into the sewer. Cleanouts are so placed that congealed grease can readily be removed from the trap. Some types of grease traps are so made that the outside wall is a water-jacket and all water used in the kitchen must run through this jacket, thus keeping the trap cool and cooling all hot grease that is discharged into the trap (Fig. 7). The size of the trap is governed by the volume and temperature of the waste water tributary thereto.

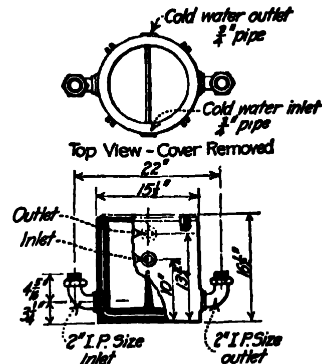


Fig. 7.—Grease trap.

12. Chemical Installations.—The big problem in chemical plumbing is the matter of waste pipes and waste pipe joints. The hot and cold water, gas, and air pipes require only special arrangement to supply the particular equipment of the individual laboratory. Lead pipe for waste in a chemical laboratory is the best waste pipe that can be had. Any connection in any position and to any material can be made by using lead and employing a lead burner to make joints and fit lead correctly. All joints on lead pipe are burned or fused by using a compressed air and hydrogen flame. This flame will not oxidize the molten lead, and is the only flame in use today that makes a perfect fusion of lead. The fusion of lead joints in this way makes the waste pipe one solid piece of lead, no other metal being used to come in contact with chemicals. Pure lead pipe of heavy gage is used. Fiber pipe has good points, such as the resistance of acids, and can be had in different sizes and lengths. The joining of pipes and lack of fittings make it hard to install.

13. Lead Burning.—The art of lead burning is not generally understood and therefore its good points are lost where they could be of great value. The mechanic who does lead burning is called a "lead burner." Lead burning is fusion welding. Hydrogen and compressed air flame are used for this fusion. Hydrogen is generally made in a generator on the job, sulphuric acid and zinc being used. Compressed air is obtained by means of hand pump and tank. Hydrogen can be purchased in a tank and used to advantage on small installations. Joints on lead pipes and lead-lined tanks can be made in almost any position. With a perfect neutral flame

and lead kept clean, a perfect fusion takes place while burning, and if the process is well done, the result is a tight, strong joint.

14. Plumbing Fixtures.—Plumbing fixtures should be located in a well lighted and ventilated room. When a single fixture is installed, it should never be in a dark part of a room and never in a closet. Fixtures must be so set that there will be at all times a circulation of air around them and daylight entering the room through side windows or ceiling lights. The material of plumbing fixtures must be of nonabsorbent nature, smooth surfaced, and sufficiently strong to withstand hard wear.

14a. Water-closets.—Every closet bowl should be flushed by clean water either automatically or by hand. Materials of bowls are iron-enameled and earthenware. The latter presents the more sanitary surfaces. Flushing of bowls with water is essential. All exposed interior surfaces must receive a thorough flushing after use.

There are two methods for flushing bowls: (1) by use of closed or open tank, and (2) by direct pressure using slow operating (flushometer) valve. To flush bowl thoroughly, scour it and refill trap, an amount of water equal to from 3 to 7 gal. being used, depending upon the type of bowl and flushing medium.

To carry off local bowl odors there is provided in some makes of bowls a connection called a local vent. This can be extended, using sheet metal pipe, to a draft flue, or connected with a duct to which is attached a fan for positive draft. All groups of toilets should be provided with a positive agency for disposing of local odors.

Essential factors in water-closets are: (1) Design and materials, (2) flush, (3) maximum water surface, (4) minimum fouling surface, (5) size of trap, throatway, and outlet, and (6) amount of water required to produce effective flush.

14b. Urinals.—Urinals may be divided into three classes: (1) wall fixture, (2) stall, and (3) trough. For the owner, urinals present one of the most disagreeable fixtures to install and operate satisfactorily. The wall fixture is at its best a somewhat unsanitary device. As a fixture it completely performs its functions of flushing and discharging waste, but it is not of proper design nor large enough to completely handle all necessary conditions.

The trough urinals present the same objections, while the stall urinal 3½ to 4 ft. high and 2 ft. wide, with a flushing surface its entire length and width, is nearest to ideal and should be selected for installation. With each discharge of the flushing device the urinal should receive a thorough flushing with clean water. This discharge may come from a tank having intermittent flushings or by means of a flush valve, operated by hand when necessary. The best designs of urinal are: (1) having complete flushing of surfaces exposed, (2) made of a nonabsorbent material, (3) entire fixture in one piece, and (4) provided with effective local ventilation.

14c. Lavatories.—Lavatories may be divided into two classes: (1) types which have backs and ends and are supported from walls, and (2) those on pedestal and which have no backs and ends. Each type has numerous styles and can be assembled to fit any desired space. The lavatories in the first named class should be used where the walls of rooms are of an absorbent material. The pedestal lavatories are used in rooms having tiled walls and floors. Any style faucets and waste can be fitted to please the owner. The materials of which lavatories are made are cast-iron enameled, vitreous, and earthenware. All these meet with sanitary requirements if correct manufacture is carried out.

14d. Bath Tubs.—Bath tubs may be classed as *built-in* and *portable*. The built-in tub is finished with an apron on one, two, or three sides, brought down flush with floor and walls. The portable tub sets on legs or base and at a point about 2 in. away from the walls. Tubs can be fitted with numerous kinds of waste and supply trimmings. They are manufactured in standard sizes in lengths of 4½, 5, 5½, and 6 ft. over all, and 30 in. wide.

14e. Showers.—Showers are divided into three groups: (1) receptor, (2) stall, and (3) tub. The receptor shower is set flush with or on top of the floor and receives the discharge from shower spray; a curtain around the spray confines the water to the receptor. The receptor is connected with the waste pipes the same as in a bath tub. The stall shower can be fitted with any desired spray and placed in a stall of marble or slate about 3 by 4 ft. square. The floor of the stall should be of cement or tile and slope toward the waste outlet. Under this floor should be placed a lead pan, built in, to catch and drain off any leakage through the

floor. The tub shower is a set of sprays set above the bath tub, with the tub acting as a receptor.

14f. Sinks.—Sinks are numerous in design, and almost any desire on the part of the owner can be fulfilled. Kitchen sinks can, for example, be had: (1) with flat rim; (2 roll rim; (3) back, end and sink in one piece; (4) sink and backs separate; (5) without or with drain boards; (6) enameled iron; (7) earthenware, white, brown, or yellow; (8) soapstone; and (9) combination of sink and wash tubs. Other sinks, such as cast iron for basement use and slop sinks for cleaners' use, have sizes and shapes to fit all needs.

14g. Special Types.—Fixtures of special types can be had to accommodate various buildings. Hospital fixtures should receive careful study, as every hospital has needs peculiar to its demands. Kitchen equipment that connects with waste pipes in hotels and restaurants are all special and should receive careful study.

15. Securing and Hanging of Fixtures.—Securing and hanging marble, slate, and soapstone fixtures are given too little thought. These fixtures must be set very rigidly. The material should set into the walls and floor about 2 in.; and all stops, hinges, and brackets should have at least two holes and bolts to hold them firmly. Fixtures of these materials should not depend upon the wall brackets for entire support but should have a support extending to the floor.

Iron enameled ware may be hung from the wall by means of concealed brackets and hangers. The concealed hangers are flat pieces of cast iron designed to be secured to the woodwork back of the plaster; therefore, before plaster is put on, solid woodwork should be securely fastened into building material to provide anchorage for enameled ware fixtures. Enameled ware is easily secured to waste pipes and usually no trouble is experienced in making water- and gas-tight connections.

Earthenware fixtures should be supported from the floor. In making this ware tight with the waste pipes, only those connections which do not depend in the main upon putty or slip joints should be used.

Vitreous ware is becoming more popular for plumbing fixtures as it presents a very hard surface. It will stand tests of great severity and is not as heavy as earthenware. Vitreous is harder than earthenware and will not chip as easily as iron enameled.

16. Swimming Pools.—Swimming pools interest the plumbing trade insofar as supplying water and waste pipes, also lead lining, are concerned. The tank needs to be so constructed that it will be water-tight. Every such pool should be supplied with a gutter or overflow all around the tank interior to carry off the scum and surplus water. To supply the tank with water at the right temperature requires a heater which will circulate the water in the tank and through the heater at the same time. The water should enter the tank or pool at the top, circulate through the tank and leave the pool at the bottom. If possible, the pool should be provided with two outlets and inlets on each side. Modern pools usually are equipped with water purification appliances.

17. Hot Water Consumption and Heating Mediums.—Equipment for hot water service is chosen generally for the needs of each particular building. After the quantity of water to be used per hour has been estimated, the necessary equipment may be chosen. Upon the demand and the service required depends the kind of equipment to be installed. If 500 gal. of water needs to be heated and drawn within 1 hr. of the day, an equipment is installed entirely different from that required if this amount of water is spread over a period of 10 hr. The various agencies for heating water are: (1) coal, (2) gas, (3) steam, (4) solar, and (5) electric (for small quantities).

Coal.—Domestic coal fires such as the range and furnace and similar heaters, may be equipped with a brass or wrought-iron coil or cast-iron water-back to heat water. In the case of the range, a cast-iron water-front is placed in one side of the firebox, which will supply sufficient hot water for one sink, one wash tray, one bath tub, and one lavatory when connected with a 40-gal. boiler. A cast-iron water-front will heat a 40-gal. boiler within 1 hr., while a brass coil placed in the same position will heat 40 gal. within 40 min.

When a coal stove or heater is used as a separate heater for hot water, a large tank should be used for storage. To determine the size of the storage tank for a building, it is necessary only that the number of outlets that are to be opened in a given period, say 1 hr., be noted; their total discharge will indicate the necessary number of gallons

that must be stored in the hot water tank. The greatest amount of hot water used in the ordinary building or dwelling will be drawn the first hour in the morning. Each person in the dwelling will use in the first hour 2 gal. of hot water in the lavatory, and, if a bath is taken, 30 gal. more. In the kitchen, 5 gal. will be used per person, making a total of 37 gal. of hot water per person for the first hour in the day. With five persons in the family, the required amount of hot water will be 185 gal.—almost a prohibitive amount for a storage tank in a dwelling. Deduct the 30 gal. for hot bath and add 2 gal. to use in the lavatory and the amount required will be 45 gal. per person per hour, which is about the correct amount used and allowed for. The foregoing example illustrates how the necessary quantity of hot water required may be determined.

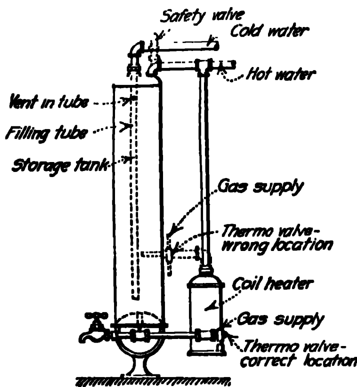


Fig. 8.—Storage tank with thermostatic control and gas heater.

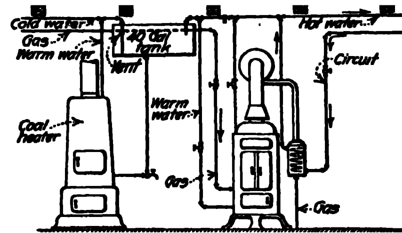


Fig. 9.—Instantaneous gas heater (in conjunction with coal heater).

Gas. —Gas used as a fuel for heating water for domestic purposes is very efficient if copper coils are utilized. Gas is used to good advantage in a storage tank heater. Gas keeps lighted until the tank is full of hot water, then automatically shuts off. Gas is also used in instantaneous heaters which supply hot water at the rate of 4 to 8 gal. per min., and will raise the water 50 deg. while it is running through the copper coils. The best method of installation for an instantaneous heater is to equip it with a booster connection and circulate the water (Figs. 8 and 9).

Solar Heat.—In some parts of the country, water is heated for domestic use by means of solar heaters, the heat being derived from the sun's rays directed through glass on to pipe coils and tank. Such systems are becoming increasingly common on the Pacific coast for residential hot water purposes. The method is satisfactory for small installations.

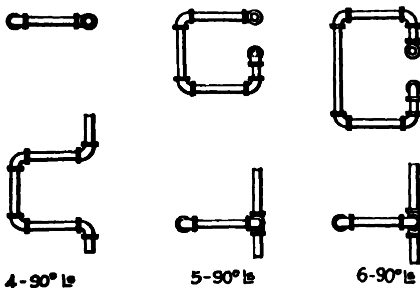


Fig. 10.—Expansion loops.

Tanks.—Tanks used for the storage of hot water are made of galvanized iron and steel, black iron, or copper. The latter makes the best installation. Galvanized iron or steel is used on small installations and black iron is used on large installations.

Circulation.—Circulating systems are used in most installations where good service is essential. This system provides for a pipe to be run from source of hot water direct to fixture or group of fixtures, also for a pipe from fixtures back to source of hot water. This allows hot water to circulate through the pipes and hot water is continually at hand within 2 ft. of the faucet.

Expansion must be allowed for in all hot water lines of pipe, either by swing joints or loops. Fig. 10 shows some types of expansion joints which may be used. These joints are made from fittings and pipe used in piping systems.

Thermostatic control of temperature of hot water should be arranged on every system. The saving in cost of fuel will soon pay for the installation of the equipment. The correct location of the thermostatic control is the first point to consider. Where storage system is used, the thermostatic member must be located at a point in the storage tank that will allow the full

capacity of the tank to be heated. Fig. 8 shows the incorrect location (dotted lines) of thermostatic control and the correct location (full lines). This equipment is fully as efficient in the saving of coal by regulation of drafts as it is in the saving of gas. The location of the thermostatic member in an instantaneous gas heater should not be in the hot water coils or next to the gas flame, but should be regulated by the temperature of the water as it leaves the heater. In storage systems where steam is used to heat water, the thermostatic control should be located away from steam pipes.

18. Cold Water Consumption, Valves and Piping.—One of the first functions of water supply to plumbing fixtures is to flush properly and cleanse the fixture after use. Fixtures which are not so designed as to distribute the supply of water over its surface are soon cast aside and replaced by fixtures which will more efficiently use the water supply to cleanse the surfaces. The water supply of a building must, therefore, be in such quantities and under such pressure that all fixtures on all floors will have at all times ample supply to meet properly the demands made upon any one or all of the fixtures.

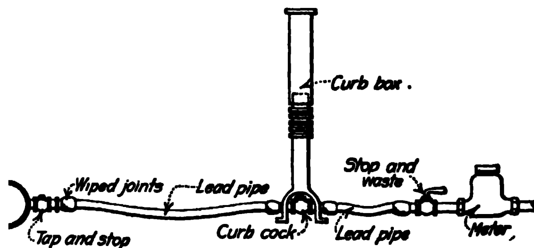


Fig. 11.—Typical water service pipe.

Main or Service Pipe.—Under the plumbing equipment of a building comes the installation of a supply water main, or what is known to the trade as a service pipe. The plumber must attend to the necessary permits before the service pipe is laid. The permits required are as follows: (1) permit to excavate street; (2) agreement to pay for all water used, which must be signed by the property owner; (3) permit to tap main pipe. For ordinary dwellings a ½-in. tap is put in by the water company or municipality, as the case may be, and a service pipe not smaller than ¾ in. should extend into the building. The service pipe must be laid below the frost line. The necessary valves, etc., required on every service pipe are clearly shown in the accompanying sketch (Fig. 11). The essential points to be considered in the installation of the service pipe are: (1) permits, (2) size of service pipe, (3) lead connection, (4) location of valves, (5) pressure carried in main, and height of building, (6) quantity required for a given period, and (7) protection against frost.

Trench.—The trench for the service pipe must be made at right angles with the curb line. The trench is started 2½ to 3 ft. wide at the top and is tapered down to a point below the level of the frost line. It is not necessary to open a ditch the entire length of the service pipe except in the street where the entire section of street must be dug full depth. On private property, character of soil permitting, the ditch may be 10 ft. long, then 10 ft. can be tunneled; then 10 ft. more opened and 10 ft. tunneled, until the entire length is covered.

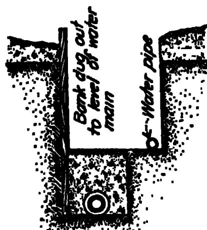


Fig. 12.—Refill of sewer and water trench.

The refilling of the trench is an operation which should receive more attention. Too often it happens that after a trench is refilled a number of barrels of dirt are left over and carted away. The result is that after a few months, perhaps after the building is completed and in use, and walks laid over the trench, the earth will settle in the trench causing the walk to cave in. The refill of a trench should use all of the dirt taken out, and will do so if water is used to settle the dirt, or if 6 in. of dirt is thrown in and tramped, and then 6 in. more added until the trench is filled. In some cities the contractor is not allowed to refill a trench without having present a city inspector. To save excavation the water service may run in the same trench as the sewer pipe if the trench is dug similar to that shown in Fig. 12.

Stops, Valves, and Piping.—The valves necessary on a service pipe into the building are: (1) brass stop at tap, (2) brass stop at curb, and (3) brass stop and waste located inside the foundation wall. These valves are in such a position that their replacement involves expense and difficulty; therefore the best materials should be used. The valves underground should be

surrounded with well-tamped earth, and care should be taken to see that valves are in an upright position.

Every fixture or isolated group of fixtures in a building should have a separate supply pipe extending from basement main to faucets. The main in the basement should be located on that side of the building which has the most fixtures. All risers should extend up through the building on inside partitions, and where possible should run in prepared chases with removable front. All water pipes in a building should be grouped together as much as possible and every riser should have a separate shut-off.

Material for exposed and concealed water pipe varies according to the action of water upon the material. Some water attacks lead more than it does brass and iron; therefore it is best to install piping which is especially suitable in resisting the action of water. Brass pipe in most cases will last longer as a water pipe than any other material. It will be found much cheaper to install good material for water pipes in the first instance than to be obliged to replace good material within 5 or 6 yr., which is often the case. Lead pipes extra strong, brass pipe (iron pipe size), galvanized iron and galvanized steel pipe are in use under all conditions, and each material has its advantages over the others for particular work. All piping which is concealed in cinder fill or concrete should be painted one coat with red lead and oil, or be asphaltum coated, and then covered with tarred paper. When water pipes pass over decorated ceilings (which should never occur if possible to avoid) they should run in a lead or copper trough which should have a tell-tale pipe extending to the basement. The best installations of water pipe are those in which the entire system is arranged for inspection.

The valves used on a system of water piping are generally gate valves, compression, globe, and plug cock. These valves are used to stop the flow of water and are called stops; when provided with a waste port to drain the piping from which the pressure has been shut off, they are called stop and waste cocks. Valves should never be placed in a line of pipe in such a position that they cannot be taken out and renewed. There are numerous maker of valves in as many different weights but of the same size. It is well, therefore, to specify the weight of valve to be used. Valves which control the water pressure to fixtures should be so placed in the system of piping that they can easily be reached at all times.

Water Hammer.—The pounding noise sometimes heard in water pipes, known as water hammer, is caused (1) by a loose packing, stems or working parts in a valve or faucet vibrating as the water passes through it, or (2) by self-closing cocks not properly fitted. There should be at each end of the water pipe lines a vertical extension of pipe about 2 ft. long and capped so as to form an effective air cushion.

DRINKING DEVICES

By Frank R. King

19. Hygienic and Some Service Features of Bubbling Fountains and Other Drinking Devices.[1]—Bacterial diseases may be transmitted by water and drinking devices. That this may be better understood and the responsible factors linked together and both studied from the viewpoint of disease prevention, the following important factors are presented.

Bacterial Diseases.—Any disease which is caused by bacteria can be passed along to someone else provided a means of transfer is afforded. As an illustration, tubercle bacilli may be conveyed by the spray from one who is coughing, by dust or by handshaking. Typhoid baccilli may be passed from one to another by handshaking, by contact, or soiled linen, in water or food.

Water.—What part does water play in carrying germs from one person to another? In order to answer this question it will be necessary to consider how disease-producing germs may get into water or on utensils used in conveying the water.

Drinking waters are classified as safe or unsafe, the former being free from the addition of sewage, household and industrial waste, or other pollution. All surface water in areas of human habitation are, as a rule, unsafe for drinking purposes without some sort of treatment. Springs which are fed by surface washings, and particularly those which emerge at the foot hills, are also liable to become polluted. Shallow wells, streams, rivers, and lakes, which receive water from surface drainage, are as a rule not safe to drink without treatment.

Water and Bacterial Diseases.—The water supplied from such wells is apt to be highly polluted, containing a large number of bacteria and other objectionable material. The surface washings and underground seepage which find their way into such a well, drain directly or indirectly from outhouses, barns, and other refuse.

[1] Extracts are taken from an investigation report entitled "Water Supplies and Drinking Devices, How They May Spread Bacterial Diseases," by Dr. W. D. Stovall, Bacteriologist, and Frank R. King, Domestic Sanitary Engineer, Madison, Wis.

Disease-producing bacteria are thus conveyed into the water supply. People drinking and using water so polluted are very frequently troubled with diarrheal diseases, typhoid fever, and other intestinal and digestive complaints.

Drinking Devices.—As a result of the concentration of people in cities, public buildings, places of employment, schools, parks, etc., the danger of the transmission of diseases caused by bacteria is greatly increased. The spread of disease is not wholly confined to the water at its source of supply, but depends frequently upon the means by which each individual obtains a drink.

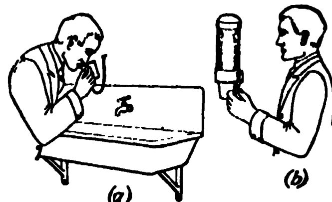
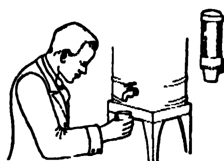


Fig. 13.

The water supply, when polluted at its source, is usually responsible for the spread of such diseases as typhoid, cholera, and dysentery. Other diseases, syphilis, tuberculosis, diphtheria, tonsilitis, and pneumonia, are frequently spread not by the water but by the depositing upon drinking devices of mouth secretions and sputa of people who are carrying the germs which cause these diseases. The old common drinking cup still is one means by which these diseases are frequently spread.

Common Drinking Cup.—In factories, in railroad stations, on railroad trains, in public parks and public buildings where not prohibited, it is the rule to see a tin cup tied to the water cooler (Fig. 13), and everybody is invited to come and have a drink from the same cup. This cup is used by the sick and well; by those who have syphilis and other communicable diseases, and by those who have not. The man with syphilis at some time during the disease usually has sores in his mouth. These sores grow from small ulcers in the throat and mouth to large ulcers which involve the inside of the cheeks, the gums and the tongue. The sores are open, that is raw, and the saliva and secretions from the mouth of such a person carry the germ which causes syphilis. When he or she drinks from the common drinking cup, there is deposited around the side of the cup saliva from the mouth. Sometimes indeed the cup dips into or rubs sores, and some of the dead tissue always lying loosely on the surface is left on the side of the cup. The next person who drinks puts into his or her mouth the same cup, rubs the infected surface maybe on a crack in the lip or a small sore on the tongue, and, as a result, acquires syphilis. This illustrates how the common drinking cup often serves to transfer disease from one mouth to another.


Fig 14.

Individual Drinking Cup.—In order to stop this means of spreading disease, many new and ingenious methods have been devised. Individual drinking cups of various types made of paraffin paper are frequently seen. These individual cups are the very best means afforded to obviate the dangers of the common drinking cup, and are inexpensive. Not a few public water fountains have a special mechanical device for distributing paraffin cups. This device consists of a long glass tube, which, after being filled with cups, is set into a container provided with a simple mechanism which is operated by a small lever on the side, delivering a cup at each operation (Fig. 14).

Bubbler Fountain.—Another popular way of supplying drinking water in public places is through the bubbling fountain. The fountain flows continuously or is supplied with a hand-operated control valve. The object of the bubbling fountain is to supply each individual with a drink without the necessity of bringing the lips in contact with the drinking device. Therefore, if the fountain meets these requirements, the stream must bubble high enough so that the water can be drunk without the lips coming in contact with the bubbler head (Fig. 15*a*).

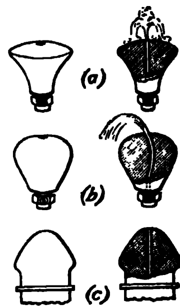


Fig. 15.

There are various types of these bubblers. Nearly all of them deliver the stream of water in a vertical direction. A later type of bubbler delivers the water at an angle of about 45 deg. (Figs. 15*b* and 18).

A recent make, "Vertico Slant," delivers the stream at an angle of 8 deg. (Fig. 19). The

special sanitary feature of this type lies in the slanting stream. This hygienic feature is intended to prevent contact of the mouth and bubbler devices. Some fountains are constructed so that the water stagnates inside the bubbler head (Fig. 16c). This is considered an objectionable feature. In other styles the fountain is constructed with a bowl which retains water and frequently the individual drinks from a pool of water which has furnished many others with a drink. This is little or no better than the common drinking cup (Figs. 16a and 16b).

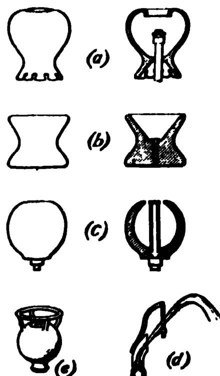


Fig. 16.

Some types have been constructed to give a flow at an angle from the bubbler and are equipped with a guard on the side (Fig. 16d). This guard may be objectionable. Many who attempt to drink from this type of bubbler place the face against the guard. This affords a means for the spread of disease by contact.

Bubbler heads equipped with small pads of cotton or other material to act as a filter for the water are not satisfactory. The cotton collects bacteria and dirt, and may actually increase the number of bacteria in the water after it passes through the bubbler.

Portable drinking fountains are often found in public places where running water is not available. Fig. 17(a) illustrates such a type. A constant pressure sufficient to force the water the desired height above the bubbler head usually is not obtained in these fountains (Fig. 17b), and as a result the lips are often placed against the head of the bubbler in order to obtain a drink. Those bubblers of this type, having inadequate pressure, are perhaps but little better than the common drinking cup.

The individual drinking cup as already described in Fig. 14 should take the place of this type of drinking fountain.

The important considerations in operating bubbler fountains are adequate water supply, uniform pressure, and cleanliness. The pressure should be adequate to force the stream sufficiently high so that the drinker may "bite" the bubbling stream. The bubbler head should be of as plain construction as possible. Of the vertical stream type of bubbler, the mushroom head type is the most satisfactory (Fig. 15), and when sufficient volume and pressure of water are supplied the angle at which the stream bubbles makes little difference.

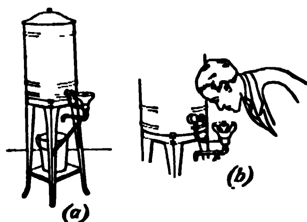
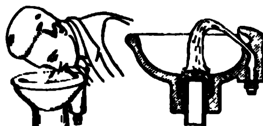
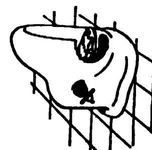


Fig. 17.


Fig. 18


Fig. 19.

PLUMBING AND DRAINAGE—TYPICAL REGULATIONS AND SUGGESTIONS

By Frank R. King

A modern system of sanitary plumbing is an influential factor in maintaining and extending the hygiene of the home, school, office, or industry, and contributes to the maximum comfort of those who enjoy its advantages. It is now recognized more than ever before as a necessary sanitary improvement. Conversely, insanitary plumbing installations are inimical to the health and well being of the public. It is considered necessary, therefore, to protect those who are not familiar with the principles of safe plumbing construction against incompetent or indifferent persons who, in the absence of official restrictions, might take advantage of such ignorance to design or install plumbing, water supply or drainage systems which may be a constant menace to health and comfort.

To this end, state and municipal regulations and ordinances have been enacted to guard against inefficient installations.

In the absence of regulations and ordinances, it is advisable to follow the Recommended Minimum Requirements for Plumbing in Dwellings and Similar Buildings, as prepared by the U. S. Bureau of Standards, in 1924.

20. "Outside-of-building" Regulations.—The following are typical requirements in a local plumbing ordinance capable of being applied to the average municipality. This measure defines plumbing and drainage and covers such subjects as inspection and supervision, licensing, permits, fees, bonds, penalties, construction and materials of house drains from building to street mains, and other phases of the work. For plumbing ordinance requirements within the building, reference should be made to Art. 22 dealing with requirements of modern codes.

Plumbing Defined.—For the purpose of ordinances, plumbing may be defined to be the placing of all plumbing, water supply and drainage materials and appliances within any building and from 3 to 5 ft. outside of the building, and the construction and alteration of all pipes, faucets, tanks, valves and other fixtures by and through which water supply or waste or sewage is used or carried in any manner whatsoever.

Drainlaying Defined.—Drainlaying for the purpose of ordinance requirements may be defined generally to include the connecting of drains to the main sewers in streets or alleys, placing of materials, construction and alteration of drains, beginning 3 to 5 ft. from the foundation or area wall of the building, to its connection and the main sewer in the street, alley or other disposal terminal.

Inspection and Supervision.—The plumbing inspector, under the direction of a state department or municipal governing body, usually has control of the supervision and inspection of plumbing, drainage and drainlaying, and is required to enforce all laws, ordinances, and rules in relation thereto. It is the duty of the plumbing inspector to see that the construction, re-construction and alterations of all plumbing, drainage and plumbing ventilation installed in all buildings coming under the jurisdiction of the state or local regulations conform with the laws and ordinances and the rules and regulations laid down by the state or local governing bodies. When ordered by the state or local authorities, he is empowered also to inspect water services as to their depth below grade, manner of construction, materials and workmanship, replacing of earth, pavements and sidewalks, and to supervise public sewer work, sewer connections, and excavations made for the same.

Plumbing and Drainlaying Permits and Fees.—Under local ordinances, and sometimes under state regulations, no plumbing may be done, except in case of repairing leaks and stoppages, without a permit first being issued therefor by the inspector of plumbing and the payment of the proper fees. When necessary the applicant for a plumbing or drainlaying permit must file with the plumbing inspector a plan and specification showing in detail the work to be done. Before the inspector issues such permit he must approve the application and issue to the applicant a statement showing the fees to be paid for such permit. Upon presentation to the plumbing inspector of the proper receipt showing the payment of all legal fees, the permit is issued for the work set forth in the application.

Schedule of Fees.—The schedule of fees to be paid varies in different cities. A typical fee schedule follows: For each sewer connection and for the first 6 fixtures, 50¢ each; and for each additional fixture, 25¢. Such schedule applies to the following list of fixtures: Sinks, water-closets, baths of any description, soda fountains, refrigerators or ice boxes, sanitary bubblers, catch basins or similar receptacles, machine waste connections, acid tanks, sumps and ejectors, rain-water cistern connections, private sewage disposal plants, changes and alterations where inspections are necessary, and house drain, sewer, water, and fire protection installations when no plumbing fixtures are installed. In some places a flat rate is charged for water and sewer connections, based on the size of the pipes to be installed.

It is usually required that no plumbing or drainage of any character, except leakage repairs and stoppages, shall be installed unless a permit for the work has been issued by the plumbing inspector, and that no person shall interfere in any way with the work of inspection, or permit any plumbing or drainage to be used until it has been inspected and approved by the inspector, unless special permission is given by the proper authorities.

Plumbers' and Drainlayers' Licenses.—Most municipalities, and some states, require that no person, firm or corporation shall carry on the business of plumbing or drainlaying, or perform such work until licenses and permits have first been obtained as required by law or ordinance, except that property owners or their employes shall not be prohibited from removing stoppages in waste pipes or repairing valves or faucets without a permit.

Bond.—Those coming under the provisions of such ordinances are usually required to execute a good and sufficient bond, with two or more sureties, or an indemnity bond, to be approved by the governing bodies, conditional upon the faithful performance of all work in accordance with the laws, ordinances, rules and regulations governing the installation of plumbing and drainage.

Authority to Enter Premises.—The plumbing inspector should have power and authority at all reasonable times for any proper purpose to enter upon any private or public premises and make inspection thereof, and to require the presentation of the license and permit of any persons doing plumbing or drainlaying work. Anyone resisting or obstructing any lawful exercise of authority by the plumbing inspector is made subject to a penalty.

Notice for Inspection.—Whenever any work is ready for inspection the plumbing inspector must be notified by the plumber in charge or persons receiving the permit, as directed by the plumbing inspector, specifying the street and house number when possible, and the plan or permit number under which the work is being done. Unless otherwise specially permitted by the inspector, all work of plumbing or drainlaying must be left uncovered for examination and approval by the inspector. The plumber should make such arrangements as will enable the inspector to search all parts of the building readily, have present the proper apparatus and appliances for making the tests, and furnish all materials and perform all labor in making the tests.

Replacing Street Surface.—When opening any street surface or other public way, all material for paving or ballasting should be removed with the least possible loss of surfacing material, and, together with the excavated material, should be placed where it will cause the least inconvenience to the public, and all such materials should be so placed as to admit the free passage of water along the gutters. As little of the trench as possible should be dug until the slant or junction piece to the sewer is found. The backfilling should be puddled, and the paving and ballast replaced in as nearly the original condition as possible and to the satisfaction of the officials. When the

sides of the trenches will not stand perpendicular, sheathing and braces should be used to prevent caving. When caving occurs, all the street surface thus disturbed should be restored in the same careful manner as though it were an excavation or a trench.

Protection of Public.—Every plumber and drainlayer should enclose openings made in streets or public ways with sufficient barriers, and maintain red lights from sunset to sunrise, one placed at each end of openings in streets and the others at intervals of 10 ft. All necessary precautions should be taken to guard the public effectually from accidents or damage to persons or property from the beginning to the end of the work. Plumbers and drainlayers should be held responsible for all damages, including costs incurred by the municipality or owner in defending any action that may be brought for damages, and costs of any appeal that may result from any neglect of the plumber or his employes to take necessary precautions against possible injury or damage to persons or property.

Record of Drain Junctions.—The city engineer is usually charged with keeping a record of all sewer connections on maps showing their location and the position of all house drains, connections, and junctions, and presenting other necessary data. No person except licensed drainlayers should be permitted to tap or make connection with the general sewerage system or any part thereof. Such information as the municipality has with regard to the location of sewer junctions or slants should be at the disposal of drainlayers, but at their risk as to its accuracy. When in compliance with the measurements furnished by the municipality the junction is not found, a slant connection and one-eighth bend should be used, and such connection made under the direction of the plumbing inspector or other authorized official.

Drain for Each Building.—Whenever practicable, the sewerage and drainage system of every house orb uilding should be separately or independently connected with the street sewer, except that where a building stands in the rear of another on the same lot, the house drain from the front building may be extended to the rear building, barn, or private garage.

Size, Quality and Weight of Materials.—The drain pipe extending from the main sewer to a point within 3 to 5 ft. of the outside wall of residences of not more than two stories, should be constructed of 6-in. vitrified clay pipe or 4-in. cast-iron pipe, and in all other cases drains extending from the main sewer to the outside or to the area wall should be constructed of 6-in., or larger, vitrified clay pipe or of 6-in. extra heavy cast-iron pipe.

Defective or Inferior Pipe Prohibited.—Ordinances usually forbid the laying or connecting with any public sewer of pipes that are cracked, damaged, or of inferior make or quality, under penalty.

Grade of Drains.—All drains outside of the building from sewer to lot line and designed to receive solid substances, should have a grade of ¼ in. or more per foot if possible; and in no case should the grade be less than ⅛ in. per foot. Where the main sewer in the street has sufficient depth or where a lot is 3 ft. or more above grade line, the drain between the curb line and lot line may receive such greater inclination as in the judgment of the local officials may be deemed proper.

Drain Ends and Connections Guarded.—The ends of all sewer and drain pipes not immediately connected should be securely closed to prevent the introduction of sand or earth; and where the end of the sewer or drain pipe is connected with a temporary catch basin for foundation during the erection of any building or for other purposes, the drainlayer should guard the same against the introduction of sand or earth.

Construction of Joints.—All joints of sewer and drain pipes must be pointed carefully on the outside and the pipe left clean and smooth on the inside by drawing through it a swab or scraper. Along the entire length of the drain or sewer, the joints should be securely and completely bedded and covered in good quick-setting cement to prevent the escape of water, sewage or air. The mortar should consist of one part cement and two parts clean sharp sand which are to be mixed dry and wetted only in small quantities as used. The use of tempered cement in any case should be prohibited.

Change of Direction and Alignment.—All sewer and drain pipes should be laid carefully in a trench with perfect alignment where the bottom is trimmed to a perfect grade; and any deviation or change of direction from a straight run should be made by the use of proper curves and Y's. No sewer or drain pipes should be clipped where proper fittings can be used for change of direction.

Backfilling.—Backfilling should be made with due care and in a workmanlike manner, according to approved standards and methods, in order to prevent the settling of the drain or sewer.

Catch Basins and Receptacles.—All sewer and drain pipes which must be left open to drain cellars, areas, yards, drain pipes, or other places, should be connected with catch basins of brick, vitrified cement pipe, concrete, or other suitable substance, the bottom of which should not be less than 2½ ft. below the bottom of the outlet pipe. Every such catch basin or receptacle should be placed inside the line of the lot to be drained, and be properly trapped.

Old Pipe or Drain.—Whenever necessary to disturb a drain or sewer in actual use, it should not be obstructed or disconnected except by special permission of the plumbing inspector, and it is usually prohibited to make new connections with or extensions to any old drain without special permission of the proper authorities.

Drain When Obstructed.—Where the course of any sewer or drain is obstructed by water, gas, steam or other pipes or conduits, the question of passing over or under such obstruction or of the raising or lowering thereof so as to permit the construction and installation of the sewer or drain should be determined by a competent municipal official.

Permit to Connect During Freezing Weather.—In cold climates no opening in the streets for making connections with a main sewer is permitted when the ground is frozen except when in the judgment of the authorities such connection is absolutely necessary, and, if such permission is granted, the work should be done as directed by the official granting the permit.

Protecting Pipes Against Frost, Injury or Settling.—All water, sewer, drain, gas, conduits or other piping should be protected from injury, frost or settling to the satisfaction of the local authorities.

Protecting Sewers and Drains.—No person should permit any earth, sand or other solid material to enter

into any main sewer during the progress of any work in laying drains or sewers, making alterations, extensions or repairs to the same, or in connecting such drains or sewers with the main sewers.

Drains Conveying Industrial Wastes.—No factory, brewery, chemical plant, stockyards, slaughter-house, tannery or other structure should be connected by any drain or sewer with the main sewer, through which it is intended to discharge any offal, garbage, filth or other solid refuse or through which objectionable substances may be discharged into the main sewer, unless such installations are provided with approved treatment appliances. Premises should not be connected with any drain or sewer entering into a main sewer through which any obnoxious, explosive, malodorous or unhealthful liquids or substances may be discharged into the main public sewers.

Adequate Flush for Drains.—The connecting of water-closets with any drain or sewer unless means are employed for the abundant and adequate flushing of the same with clear water every time they are used, should be forbidden. Every such closet or similar appliance should be properly connected with an adequate water supply system, either public or private.

Steam or Hot Water "Blow-offs."—Exhausts or "blow-offs" from steam boilers or engines should not be connected with any drain or sewer, but should be discharged only into catch basins or an adequate cooling receptacle.

Penalty.—The following may be taken as a typical penalty provision. "Any master or journeyman plumber, drainlayer, property owner, or other person who shall willfully violate any of the provisions of this ordinance, or who shall install or allow to be installed any plumbing or drainage in this city (village) contrary to the provisions of this ordinance, shall be deemed guilty of a misdemeanor and shall be subject to a fine of not less than $10, and not to exceed $50, or imprisonment in the county jail not exceeding 30 days for each and every violation thereof. Each day of such violation shall constitute a separate offense."

21. Explanation of Terms.—*Plumbing work* embraces all piping and appurtenances in connection with the drainage, ventilation, or water supply systems within, and to a point from 3 to 5 ft. outside, the building or other parts of the structure, and may include the water service and house drain piping and appliances to the mains in the street, alley, or other terminal.

House sewer or main drain is that part of the horizontal piping beginning 3 to 5 ft. from the foundation wall to its connection with the main sewer, cesspool or sewage treatment tank, or other disposal terminal.

House drain is that part of the horizontal piping of a house drainage system which receives the discharge of all soil, waste and other drainage pipes inside the walls of a building and conveys it to the house sewer, 3 to 5 ft. outside the foundation wall of the building.

Soil pipe is any pipe which conveys the discharge of water-closets with or without fixtures to the house drain.

Waste pipe is any pipe which receives the discharge of any fixture except water-closets and conveys the same to the soil pipe or house drain.

Main soil or waste vent is that part of the main soil or waste pipe above the highest installed branch or fixture connection, extending through the roof.

Vent pipe is any pipe provided to ventilate a drainage and plumbing system of piping and to prevent siphonage and back pressure.

Back vent pipe is that part of a vent pipe which connects directly with an individual trap underneath or back of the fixture and extends to the branch, main, soil or waste pipe at any point higher than the fixture or fixture traps it serves.

Unit vent is one which denotes an installation so arranged that one pipe will serve two traps.

Circuit vent is a connection made by joining a nearly horizontal trap outlet with a waste and vent pipe in such a manner that a continuous vent is formed.

Local vent is a pipe or shaft serving to convey the foul air from plumbing fixtures or room to the outer air.

Trap is a fitting constructed to prevent the passage of air or gas through a pipe without materially affecting the flow of sewage or waste water, and which is self-scouring.

Depth of seal trap is indicated by the height of the water column measured between the overflow and the dip separating the inlet and outlet arms of the trap.

Deep seal resealing trap of the centrifugal self-scouring type is a trap in which the water motion is both centrifugal and upward at each discharge of the fixture and retains an adequate amount of water to form an efficient trap seal.

Deep seal is a term applied to a trap having a water seal twice the depth of the common trap.

Subsoil drain is that part of a drainage system which conveys the ground or seepage water from the foot of walls or below the cellar bottom to the house sewer, independent of the house drain.

Conductors or roof leaders are the pipes which carry the storm or rain water from the roofs of buildings to the house or yard, drain or sewer. The vertical portion of the conductors is usually referred to as the down spout.

Back flow is a term denoting the reversal of flow in a drainage system.

Dead end is that part or branch of a drainage system which is without a free circulation of air.

Private sewer is one which has an independent sewage disposal, not connected with a public sewer, and which accommodates one or more houses.

A sanitary sewer is a drain or sewer constructed to convey organic sewage from buildings to a septic or bacterial treatment tank or other point of disposal and from which all surface and storm water is excluded.

A septic or biological tank is a reservoir or tank which receives crude sewage, and by bacterial action, liquefication, and sedimentation effects a process of purification and clarification.

Cesspool **is an excavation in the ground made for the receiving of crude sewage, and so constructed that the organic matter is retained while the liquid portion is permitted to seep through its walls.**

Rural or isolated residences **are understood to be those situated at such a distance from public sewer system that their drainage systems cannot become tributary to such public system.**

Roughing in **is the placing of all that part of a drainage or vent system which can be completed before the plumbing fixtures are installed.**

Wiping a joint **is a method of joining two pieces of metal, in which the solder is fused on the joint and wiped to a smooth, neat finish with a wiping cloth, and having a thickness of solder over that part of the joint where the metals join of not less than one-fourth inch.**

Sanitary plumbing **is understood to denote plumbing so designed and installed that it can be kept clean—that is, free from defects in construction—and that conforms in every particular with good practice and sanitary essentials.**

Private dwelling **is understood to be any building used only for living purposes and occupied by not more than two families.**

Alignment **is understood to indicate "in a straight line," graded, horizontal or perpendicular.**

Terminal **is that part of a drainage or vent system which projects above the roof of the building or the end of the house drain connecting to the septic tank or house sewer, or other disposal terminal.**

Public building **as defined by state and local regulations means any structure used in whole or in part as a place of resort, assemblage, lodging, trade, traffic, occupancy, or use by the public, or by three or more tenants.**

Place of employment **means every place, whether indoors or out, or underground, and the premises appurtenant thereto, where either temporarily or permanently any industry, trade or business is carried on or where any process or operation, directly or indirectly related to any industry, trade or business, is carried on, and where any person is directly or indirectly employed by another for direct or indirect gain or profit, but does not include any place where persons are employed in private domestic service or agricultural pursuits which do not involve the use of mechanical power.**

Basement **may be defined as that portion of the building whose floor line is below the grade at the main entrance and whose ceiling is not more than 9 ft. above the grade. The first floor is that next above the basement, or the lowest floor if there is no basement. The total number of stories in a building is understood to embrace all stories except the basement.**

Height of building **is generally measured at the center line of its principal front, from the street grade (or if setting back from the street, from the grade of the ground adjoining the building) to the highest part of the roof, or to a point two-thirds of the height of the roof, if a gabled or hipped roof. If the grade of the lot or adjoining street in the rear or alongside of the building falls below the grade at the front, the height should be measured at the center of the building.**

Approved, **as used in plumbing and drainage ordinances, is a term usually signifying the installation is approved by state or local authorities in conformance with state laws or local regulations governing.**

22. "Within the Building" Regulations.—In this article are set forth in brief form typical plumbing, water supply and drainage requirements as contained in modern state and local codes, and rules and regulations applicable to work *within* the building.

The important "within the building" requirements in connection with plumbing, water supply and drainage systems may be summed up as follows:

(*a*) Location with reference to convenience.

(*b*) Adequate housing.

(*c*) Approaches affording due privacy.

(*d*) Proper construction of floors, walls, partitions, etc.

(*e*) Lighting, heat, and effective room ventilation.

(*f*) Kind and number of fixtures and other appurtenances.

(*g*) Design and arrangement of piping fixtures, etc.

(*h*) Kind, quality and weight of materials.

(*i*) Types of traps and re-vents necessary.

(*j*) Safe and adequate water supply.

(*k*) Good workmanship.

(*l*) Utility chambers, shafts, recesses, raising or depressing of floors, placing of walls and partitions, etc., to enable the proper installation to be made of all needed piping and appurtenances.

(*m*) Economy of installation consistent with simplicity, durability, service, comfort and sanitation.

Nearly all state and local regulations include some specific requirements for the following classes of buildings, each of which should receive careful consideration by the designer of plumbing, water supply and drainage installations:

Places of employment—factories, office and mercantile buildings, and other employment centers.
Public buildings, school buildings, libraries, museums, places of detention.
Apartment and tenement houses.
Theaters and assembly halls.
Hotels and rooming houses.
Restaurants, barber-shops.
Slaughter-houses, rendering plants.
Creameries, condenseries, cheese factories.
Chemical and similar plants.
Federal buildings.
Private residences and two-family flats.

Piping requirements are in most cases identical except as to sizes and kind of materials, where the character of the waste is such as to be destructive or where its proper disposition requires special treatment. The number and type of plumbing fixtures and other appurtenances likewise vary in certain types of buildings.

Whatever deficiencies may exist in a system, may properly be ascribed alike to the manufacturer, plumber, engineer, architect, designer, owner, installer, and inspector of plumbing. The remedy lies in education and the coöperation of all concerned.

Sewers and Drains

Section 1. (*a*) *One Drain for Each Building.*—The plumbing system of each new building, or new plumbing installation in an existing building, should be entirely separate from and independent of that of any other building, except as provided in the following section.

Wherever practicable, every building should have an independent connection with a public or private sewer.

(*b*) *Two or More Buildings on a Lot.*—Where a building stands in the rear of another on the same lot, the house drain from the front building may be extended to the rear building, private garage, or barn, and the whole may be considered as one house drain.

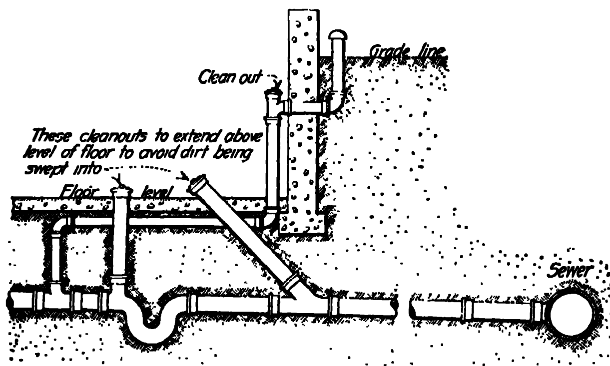


Fig. 20.

Section 2. (*a*) *Underground House Drains.*—All house drains should wherever possible be brought into the building underground below the level of the basement or cellar floor.

(*b*) *Materials Used.*—All underground house drains must be made of vitrified clay or cast-iron pipe. In some localities the use of vitrified clay pipe is permitted where the ground or soil covering is 18 in. or more, provided that where a substantial cement floor is laid, 12-in. covering is permissible. Vitrified clay pipe must not be used in the construction of a house drain when the ground or soil has not the proper stability to insure an unyielding foundation (Figs. 20 and 48).

Note.—Cast-iron pipe is always preferable to vitrified clay pipe as it is stronger and more durable. But when laid in ground or material containing cinders, ashes or ingredients that will affect cast iron, it should be adequately protected.

Section 3. *Trenches for Pipes.*—When deemed essential by state or local authorities for inspection purposes, all excavations necessary for the installation of a house drainage system or any part thereof within the walls of a building should be open trench work.

Section 4. (*a*) *Subsoil Drains.*—Where subsoil drains are used, they should be made of open-jointed drain tile, properly trapped before entering the house drain.

(For method of installation see Sect. 40.)

Table 1.—Soil, Waste and Vent Pipes

Table Showing Kind and Number of Fixtures; Sizes of Traps; and Diameter of Soil, Waste, and Vent Pipes

Kind of fixtures	Soil and waste		Vent†		Sizes of traps required (inches)	Maximum developed length of vent pipe permitted‡ (feet)
	Number fixtures allowed	Sizes of soil and waste (inches)	Number fixtures allowed	Sizes of back vent (inches)		
Closets	*	3	6	2		60
	20	4	7-10	2½		80
	21-40	5	11-20	3	2½	100
	41-60	6	21-40	3½	to	120
	61-100	8	41-75	4	4	150
	101-200	10	76-100	6		250
Slop sink with trap combined	2-	2	1	1½		40
	6	3	6	2	2	60
	7-15	4	7-10	2½	to	80
	16-36	5	11-20	3	4	100
	37-64	6	21-	3½		120
Sinks, bath tubs, laundry trays, ordinary slop sinks, small single urinals, and shower baths	1	1½	4	1½		40
	1-4	2	5-8	2		60
	5-6	2½	9-12	2½	1½	80
	7-10	3	13-20	3	or	100
	11-15	3½	21-30	3½	2	120
	16-30	4	31	4		150
Wash basins, cuspidors, bubblers, refrigerators	1	1¼	2	1¼		25
	1-4	1½	2-6	1½	1¼	40
	4-10	2	6-15	2	or	60
	10-25	3	15-40	3	larger	100
	25	4	40	4		150
Floor drains	1	2	6	2	2	60
	1-4	3	6-10	3	to	100
	4-8	4	10	4	6	150
	8-36	6				
Fountain connection	. .	*1½	. . .	1½	1½	40
	.	to	. . . .	to	or	to
	.	3	. . . .	2	larger	60
Long trough pedestal, combined trap, and porcelain stall urinals	1	2	2	1½		40
	1-4	3	1-4	2	2	60
	4-10	4	4-12	2½	to	80
	10-25	5	12-30	3	4	100
	25	6	30	4		150

* See Section 29 and Fig. 28.

† The vent sizes are intended for individual reventing of each fixture trap.

‡ After maximum developed length of vent pipe is reached, increase diameter of pipe at each multiple of the maximum length permitted.

Note.—Consult also Sections 5 to 10 inclusive.

Note.—In determining the size of the soil and waste pipe given in Table 1, allow, in addition to each closet permitted, one bath, one basin, and one sink or other similar fixture. In determining the size of vent pipe, allow, in addition to each closet permitted, one bath, one basin, and one sink or other similar fixture. (For method of installation, see various illustrations.)

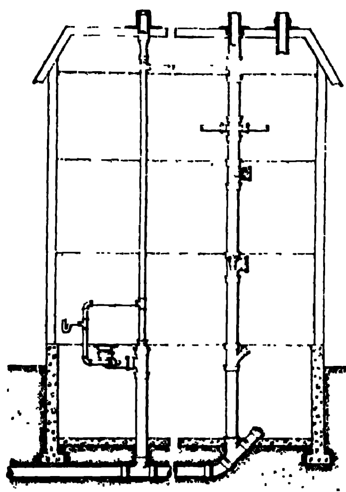


FIG. 21.—Methods of venting, roof-flashing, and locat of soil, waste, and vent fittings.

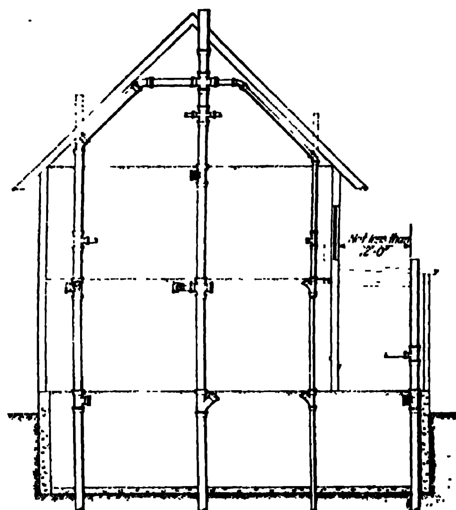


FIG. 22. -Method of connecting vent and joining of soil and waste pipe stacks.

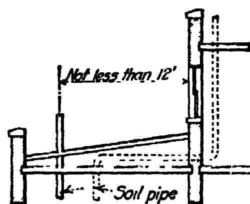


FIG. 23.

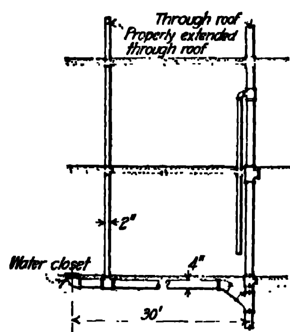


FIG. 24.

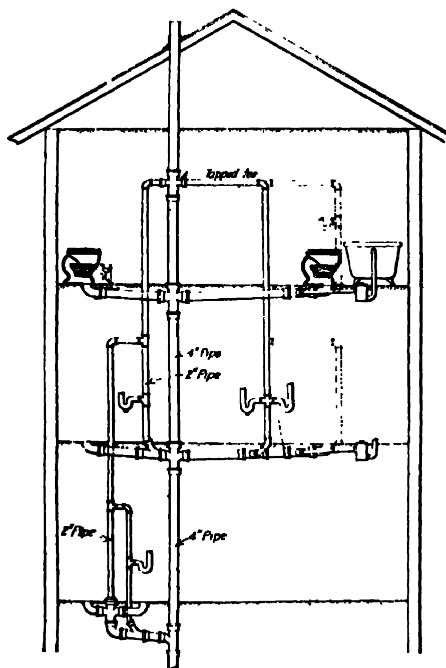


FIG. 25.

Section 5. (*a*) *Materials*.—All main and branch soil, waste, vent and back pipes should be made of cast iron coated with tar or asphaltum, galvanized wrought iron or steel pipe, or lead, brass or copper.

(*b*) *Minimum Size of Vent Stack*.—Where not more than two water-closets are installed below the first floor and serve as the only closets in the building, the vent pipe should not be less than 2 in. In determining the size of the

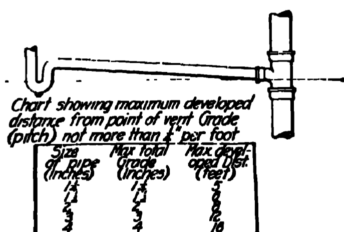


Fig. 26.

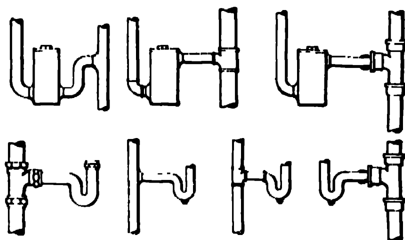


Fig. 27.—Showing methods of back-venting traps.

vent pipe, allow in addition to the closet, one bath, one basin, one sink or other similar fixture. The size of the vent and waste pipes for basins, sinks, baths or other similar fixtures when they serve as the only fixtures in a building, should be governed by the provisions of Table 1.

(*c*) *Four-inch Stack May be Decreased*.—A closet may be installed on a 4-in soil pipe rising from the house drain to first or second floor, and may be vented with a 2-in. vent pipe, provided the premises where such closet is to be installed has a 4-in. soil pipe stack of undiminished size extending through the roof (see Fig. 21).

In garages, barns, etc., a closet may be installed on the first floor or ground floor and may be vented with a 2-in. pipe.

Section 6. (*a*) *Roof Extensions*.—All soil and waste pipes receiving the discharge of any fixture should be extended the full calibre above the roof, except as provided for in Fig. 21.

In no case in cold climates should a vent pipe through the roof be less than 4 in in diameter. The roof terminals of such vent pipes should conform with the provisions of Figs. 22 and 23. Change in diameter should be made by means of a long increaser, at least 6 in. below roof (Fig. 21).

(*b*) *Protection from Frost*.—All drain, soil, waste, or vent and supply pipes should be as direct as possible, properly protected from frost, and when possible arranged so as to be readily accessible for inspection and repairs.

Section 7. *Branch Soil and Waste Extensions*. Any vertical or any horizontal branch running vertically, horizontally, or both, more than 30 ft. from the soil

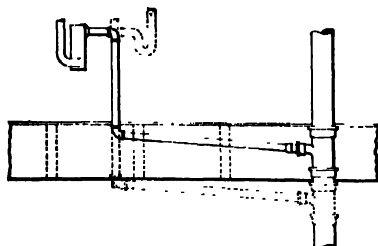


Fig. 28.

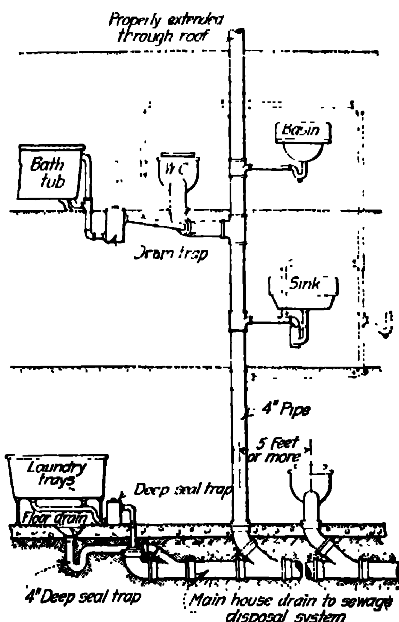


Fig. 29.

line should be continued full size to a point above the roof in the same manner as required for main soil pipes, or may be returned to main vent pipe full size (Fig. 21).

Section 8. (*a*) *Traps, Distance from Vents*. The back vent of any fixture trap should be as close to trap as practicable, consistent with its location and effectiveness (see various figures).

(*b*) *One or Two Water-closets or Similar Fixtures*.—Two water-closets on the same floor discharging into a Y or sanitary Tee cross, or one closet discharging into a Y branch or sanitary Tee need not be back vented, providing that the developed distance of the horizontal soil branch extended with a grade of not less than ¼ in. per ft. does

not exceed the inside diameter of the soil branch and the vertical the horizontal soil branch and the trap water level does not exceed 2 ft. (Fig. 25 and Sect. 10 and 19c).

(c) *Fixtures other than Water-closets.*—Two fixtures other tha losets discharging into a double Y or sanitary Tee cross or an individual fixture other than water-c Y branch or sanitary Tee need not be back vented, providing the total fall of the waste pipe between the water level of the trap and the vent pipe extended at a grade of not less than ¼ in. per foot does not exceed the inside diameter of the branch waste pipe (Fig. 26 and Sect. 10 and 19c).

(d) *Crown Vent Prohibited.*—In no case should the vent be taken off the crown of the trap (Fig. 27).

(e) *When Deep Seal Resealing Traps of the Centrifugal, Self-Scouring Type Must be Used.*

1. When a common trap is not adequate protection against sewer air.

2. When the total fall of the soil or waste pipe between the water level of the trap and the point of venting exceeds the inside diameter of the waste pipe, extended at a grade of not less than ¼ in. per ft

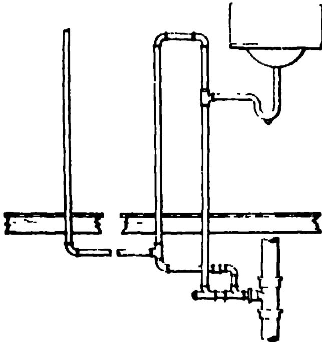


Fig. 30.—Method of installing loop vent.

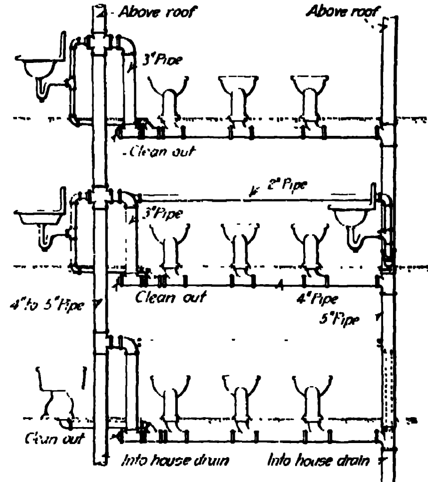


Fig. 31.—Circuit or continuous venting.

3. When it is impracticable to vent, a deep seal resealing trap should be installed. So far as is practical a free circulation of air must be provided (Figs. 28 and 29).

(f) *Vents Reconnected.*—All vents should be run separately through the roof, or be reconnected at least 8 in. below the roof, or be reconnected to the main vent pipe not less than 3 ft. above the highest floor on which fixtures are placed. No fitting for future waste connections should be placed in any soil or waste pipe above the point of revent connection (Fig. 22).

(g) *Rearranging of Vent and Revents.*—Where fixtures are afterward installed on a soil or waste line above a point where the vent or revents enter the vent or vent stack, the vent and revent pipes of the fixtures already installed should be rearranged to conform to the provisions of Section 8 (b).

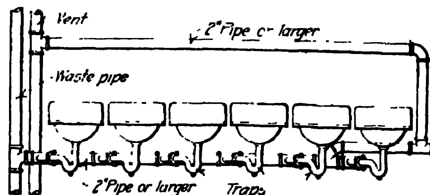


Fig. 32. Loop vent.

(h) *Vent Pipe Grades and Connections.*—All branch vent and back vent pipes should be free from drops or sags, and shall be so graded and connected as to drip back to the soil or waste pipe by gravity. Whenever it becomes necessary to trap a horizontal vent pipe, an approved method of bleeding should be employed (Fig. 30).

(i) *Fixtures Parted by Wall.*—Where bath rooms, water-closets or other fixtures are located on opposite sides of a wall or partition in the same building, or are directly adjacent to each other in two inseparable buildings, such fixtures may have a common soil or waste pipe and vent pipe stack.

Section 9. *Continuous or Circuit Vent Installation.*—Batteries of closets, urinals, sinks, basins, etc., may be installed by the continuous or circuit vent system. Loops and circuit vents should be of the following sizes: 2 in.

for a battery of two closets, 3 in. for a battery of five closets, 4 in. for a battery of six to twelve closets. For urinals, sinks, basin or similar fixtures the loop or circuit should be of the size provided for in Table 1 Methods for such installation are shown in Figs. 31, 32, 33, and 34.

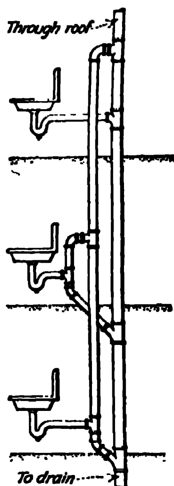


Fig. 33.—Individual continuous vent.

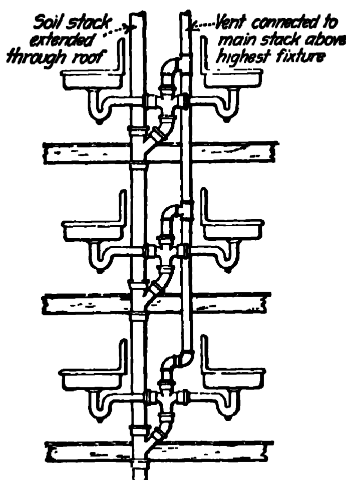


Fig. 34.—Method of circuit and unit venting.

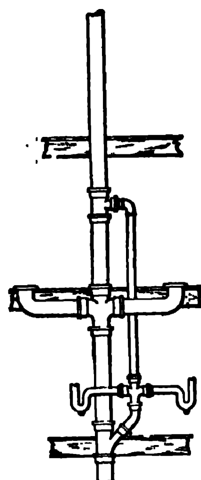


Fig 35.—Method of circuit and unit venting.

Note.—Experience has demonstrated that in order to guard effectively against trap siphonage and back pressures of air on trap seals in high buildings or in other structures where large volumes of wastes are suddenly discharged, it is essential that waste and vents of adequate sizes be provided and that the cross-sectional area of the main vent lines be equal to that of the soil or waste lines.

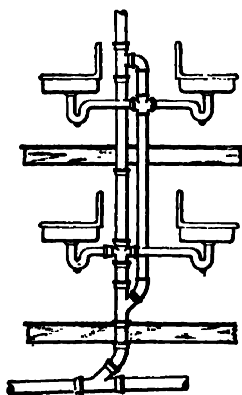


Fig. 36.—Unit vent and waste installation.

Section 10. (*a*) *Unit Vent.*—Two water-closets located on the same floor discharging into a double Y or sanitary T cross in a soil or waste stack, need not be back vented, provided that the developed distance of the horizontal soil pipe branch extended with a grade of ¼ in. per ft. does not exceed the inside diameter of the soil pipe and the vertical leg between the horizontal soil pipe branch and the trap water level does not exceed 2 ft.

Two fixtures, other than water-closets discharging into a double Y or sanitary T cross, with no other fixtures discharging above them, may be back vented through a common vent or back vent pipe provided the total fall between the water level of the trap and vent pipe does not exceed the inside diameter of the waste pipe extended at a grade of ¼ in. per ft. (Figs. 35 and 36 and Sect. 8 and 19*c*).

(*b*) *Back Vents not Required.*—Basement or cellar floor drains, subsoil traps, elevator catch basins and similar receptacles need not be back vented when branched into an adequate and properly ventilated horizontal house drain 5 ft. or more from the base of a soil pipe stack. For further provisions on this subject, see "Floor Drains and Fixture Wastes."

(*c*) *Protection against Trap Syphonage.*—Every fixture trap should be protected against back pressure and from syphonage, and air circulation insured where necessary by a vent or back vent pipe.

(*d*) *Dead Ends.*—All dead ends in pipes should be avoided in the installation of any plumbing system.

(*e*) The provisions of Sections 5 to 10 inclusive relative to soil, waste, and vent pipes (Table 1) are uniformly applicable to all buildings of ordinary height, construction, and use.

Plans and specifications for plumbing installations in hotel buildings and buildings of like construction, occupancy, and use, of a height greater than 100 ft., should be submitted to the proper body for approval, also for buildings coming under this classification where the number of plumbing fixtures to be connected to a 4-in. soil pipe stack exceeds the number given in Table 1.

The plans and specifications for such approval should contain such definite information together with the basis of design of the system as the approving body may require.

(*f*) *Basis of Design.*—Such installations must conform with the following basic principles:

1. Soil, waste, and vent pipes must be of adequate capacity and proper design and construction.

2. Distribution of plumbing fixtures must be such that not more than two toilets, two wash basins, and two bathtubs or similar fixtures will be tributary to any soil or waste stack on the same floor level except when such pipe is greater than 4 in., in which case a proportionately larger number of fixtures may be added.

3. All plumbing fixture traps shall be effectively protected against syphonage or back pressure that may cause traps to blow or fixtures to overflow.

4. The system should be so designed and installed that there will be no retarded flow or back pressures to interfere with the proper functioning of the plumbing fixtures or appliances or with the installation as a whole or to impair service and sanitation.

NOTE.—Because of the varying constructional conditions and sanitary equipment which it is impossible to anticipate, it is impractical to set forth other than the basic rules governing. Upon application accompanied by necessary information, the general requirements may be outlined, and preliminary or incomplete plans may be submitted for recommendation, but detailed plans must be submitted to the state or local department before final approval is given.

More stringent back-venting requirements than have here been outlined are contained in some plumbing codes. A few will be cited as examples:

Trap Back-vented.—"Every fixture trap shall be protected from siphonage, and air circulation assured by means of a vent or back-vent pipe."

Vents, Lengths from Trap.—"The back vent of any fixture shall be as close to the trap as practicable consistent with its location and effectiveness. The developed length of the waste pipe of any fixture from its trap to the vent pipe shall not exceed 24 in.

"For the purpose of obtaining a direct rising vent from a vertical waste line, a fixture trap immediately under a small fixture waste shall be placed not more than 24 in. from the vertical waste and vent line, measured between the center of the waste and vent, provided that the point of entry into the vertical waste line is not lower than the bend of the trap. For water-closets, pedestal urinals, and trap standard slop sinks the distance allowed between the waste opening in the floor or wall and vent or back vent shall not be more than 21 in. developed length."

Back Venting—Water-closets.—"Every earthenware fixture with trap combined shall be unprovided with a back vent horn.

"Every water-closet, pedestal urinal and slop sink having a floor connection shall be back-vented from the soil or waste branch and preferably on the top of the branch. When connected with the vertical arm of a bend, it shall be made above the top of the horizontal branch.

("This vent must rise at an angle of 45 deg. or less to vertical, to 6 in. above the horizontal branch.")

Circuit Loop and Continuous Vents.—"Every branch soil or waste pipe to which a group of two and not more than eight water-closets, pedestal urinals or trap standards slop sinks are connected, may be vented by a circuit or loop vent, provided such horizontal branch does not exceed 25 ft. in length and the fixtures are within the prescribed 24-in. limit from the branch forming the circuit vent. Connections from such branch shall be taken from Y or TY branches. The vent shall be taken off in front of the last fixture connection, and must rise at an angle of 45 deg. to vertical to a point 6 in. above the top of the highest fixture before offsetting horizontally or connecting to the branch, main, waste or soil vent.

"Where fixtures discharge above such branch, each branch shall be provided with a relief vent one-half the diameter of the soil or waste stack taken off in front of the first fixture connection and rise at an angle of 45 deg. to vertical to a point 6 inches above the highest fixture before being offset horizontally or connecting to the branch, main waste or soil vent.

"The main soil or waste stack shall be offset at every fourth story containing fixtures, immediately below the branch, soil, or waste connection.

"The soil and waste pipes shall conform to the following sizes:

Size of House Drains, Soil and Waste Stacks, Mains and Branches.—"Twenty square feet of roof or yard area in horizontal projection counts as one fixture.

"Three feet of urinal trough or wash sink counts as one fixture.

"One bath, basin, sink or smaller fixture counts as one fixture.

"One pedestal urinal or slop hopper sink counts as two fixtures.

"One water-closet counts as four fixtures.

"Dimensions given refer to the inside diameter.

"Providing that the number of water-closets on any soil pipe, with or without other fixtures, shall never exceed the number given in the last column.

"MAXIMUM NUMBER OF FIXTURES

Size of pipe (inches)	Waste, soil and waste combined (fixtures)	Soil pipe alone (water-closets)
1¼	1	
1½	3	
2	8	
2½	10	
3	20	2
3½	40	2
4	64	16
5	144	36
6	288	72
7	504	126
8	840	210
9	1160	290
10	1600	400
11	2120	530
12	2840	710

"Where it is impractical to use 4-in. soil pipe for water-closets, 3-in. soil pipe may be used for vertical stacks, and shall conform with the number of fixtures in the above table. If earthenware drains or sewers are used, the diameter of the pipe shall be increased one size over the above table.

"The main vent pipe shall conform to, and the branch vent pipe shall be one full size larger than the sizes prescribed below:

"*Size of Vent Pipe Stacks*.—The following table gives the size of vent pipes and the maximum number of fixtures that they shall serve:

Size of pipe (inches)	Maximum developed length in feet	Number of traps in 1½ or less	Number of traps 2 in.	Number of water-closets
1¼	15	1 (1¼ in trap)		
1½	25	3	1	
2	40	12	6	3 or less
2½	60	24	12	6
3	90	48	24	12
3½	130	100	50	25
4	180	160	80	40
5	210	210	140	70
6	330	480	240	120

"For 5-in. traps and over, the vent shall be one-half the diameter of the trap except as prescribed for latrines.

"If the length of a branch or main vent pipe is to exceed the given maximum, the above diameter must be increased to the tabulated size opposite the length required, irrespective of the number of traps vented, but in no case shall the main be less than one-half the diameter of the adjoining soil pipe."

Section 11. (*a*) *Grade of Horizontal Pipes*.—All horizontal drain, soil and waste pipes should be run in practical alignment and at the uniform grade of ¼ in. per ft. or more; but in no case should the grade be less than ⅛ in. per ft., whether under cellar floor or supported by piers, posts, wall ledges or iron hangers.

(*b*) *Changes in Direction*.—For information on changes in direction of soil, waste, and drain pipes, see Figs. 37, 38 and 39 and Table 3.

(*c*) *To Increase or Reduce Size of Pipes*.—Proper fittings of sanitary design should be used to increase or reduce size of pipes. (For prohibited fittings, see Sect. 16.)

Section 12 (*a*) *Hangers and Supports*.—All hangers, pipe supports and fixture settings in or against masonry, concrete or stone backing should be securely made with expansion bolts or other approved methods without the use of wood plugs. All drainage and plumbing pipes should be rigidly secured and supported so that the proper alignment will be retained.

(*b*) *Backgrounds*.—Backgrounds, except under special conditions, must be provided for the securing of closets, tanks, basins, sinks, brackets and all other wall fixtures or hangings.

(c) *Stack Supports.*—All stacks shall be thoroughly supported on concrete, masonry piers, or foot rests at their bases; and those 10 ft. or more in height should also be provided with floor rests or other substantial supports at 10 ft. or floor intervals. All pipe supports should be made of heavy iron posts, wall hangers or brackets, steel fittings, or concrete or masonry piers. All brick piers should be at least 8 in. square and laid up with cement mortar.

Quality and Weight of Materials

Section 13. *Vitrified Pipe.*—All vitrified pipe and fittings should be first quality vitrified clay pipe, sound and well burned throughout their thickness, with well-glazed smooth exterior and interior surfaces, free from cracks, flaws, blisters, fire checks and all other imperfections which would impair their value

Section 14. (a) *Cast-iron Pipe.*—All cast-iron pipe fittings should be made of close-grained gray iron, ductile and readily cut with file or chisel, smooth on the inside, free from flaws, sand holes or other defects, and of a uniform thickness. Such pipes and fittings should not be lighter than the commercial grade known as "Standard."

Note.—On account of its greater durability and ease of installation, it is recommended that "extra heavy" cast-iron pipe be used in all plumbing systems.

(b) *Weights of Cast-iron Pipes.*—All cast-iron pipe, including hubs, should weigh not less than the weights per foot given in Table 2.

TABLE 2

Diameter (inches)	Standard weight per foot	Extra heavy weight per foot (pounds)
2	3½	5½
3	4½	9½
4	6½	13
5	8½	17
6	10½	20
7	....	27
8	....	33½

(c) *Coating for Cast-iron Pipe and Fittings.*—All pipe and fittings should be coated with asphaltum or coal tar pitch. Both pipe and coating should be heated to a temperature of 300 deg. F before the castings are dipped.

TABLE 3.—SHOWING MINIMUM RADIUS OF CAST-IRON SOIL PIPE FITTINGS PERMITTED WHEN CHANGE OF DIRECTION IS MADE

(Case A) When direction of flow changes from horizontal to vertical:

Size of pipe (inches)	2	3	4	5	6
Minimum radius (inches)	3	3½	4	4½	5

(Case B) When direction of flow changes from vertical to horizontal:

Sizes of pipe (inches)	2	3	4	5	6
Minimum radius (inches)	3	3½	4	4½	5

(Case C) When direction of flow is at right angles and changes from horizontal to horizontal:

Size of pipe (inches)	2	3	4	5	6
Minimum radius (inches)	5	5½	6	6½	7

Note.—A combination Y and ⅛ bend or Y and ⅛ bend is recommended. When a pipe of smaller diameter enters a pipe of greater diameter, a fitting with a minimum radius as shown under Case A may be used.

When sanitary T's or wiped branches are used in change of direction they should be so arranged that the flow from other fixtures will serve as a wash.

For method of determining radius, see Figs. 38 and 39.

Section 15. (a) *Wrought Iron Pipe.*—All wrought-iron pipe or steel pipe, known to the trade as merchant or full weight pipe, used for soil, waste or vent pipes, should be galvanized and not ligher than shown in the following chart:

Note.—Galvanized wrought iron is higher recommended owing to its superior lasting qualities.

TABLE 4

Diameter, inches	Weight per lineal foot, pounds
1½	2.73
2	3.68
2½	5.82
3	7.62
3½	9.20
4	10.89
4½	12.64
5	14.86
6	19 18
7	23.77
8	25.00

(*a*) *Screw-thread Fittings.*—Threaded fittings for vents and back vents shall be malleable, cast iron, or brass. All screw thread fittings used for soil and waste pipes should be of the recessed, drainage fitting pattern; and the same rules for change of direction given in Tables 3 and 5 will apply. All iron screw thread fittings for soil, waste or vent pipes should be galvanized or asphaltum coated.

TABLE 5.—SHOWING THE MINIMUM LENGTH OF FACE TO CENTER OF DRAINAGE FITTINGS

(Case A) When direction of flow changes from horizontal to vertical:

Size of pipe (inches)	1¼	1½	2	2½	3	4	5	6
Distance from face to center (A), Fig. 16 (inches)	1¾	2 3/16	2¾	2 13/16	3 3/16	3 13/16	4½	5 3/16

(Case B) When direction of flow changes from vertical to horizontal:

Size of pipe (inches)	1¼	1½	2	2½	3	4	5	6
Distance from face to center (A), Fig. 37 (inches)	2¼	2½	3 1/16	3 11/16	4¼	5 3/16	6⅛	7⅛

(Case C) When direction of flow changes from horizontal to horizontal, use same distance from face to center as in Case B.

Note.—Long turn Y branches or Y and ⅛ bend are recommended.

Section 16. *Prohibited Fittings.*—Sanitary Tees of short radius should not be used except in connected horizontal to vertical soil or waste pipes in which the flow is toward the vertical line. The use of one-fourth bends or elbows in soil or waste pipes is governed by Tables 3 and 5, and Figs. 38 and 39.

One-fourth bends with side or heel outlets, except when they are made with Y or sanitary T branches, and all double hub fittings, double Tees and double sanitary Tees when used horizontally are prohibited, except when

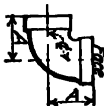
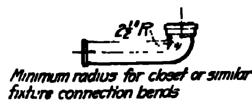
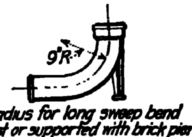


FIG. 37.



Minimum radius for closet or similar fixture connection bends

FIG. 38.



Minimum radius for long sweep bend with foot rest or supported with brick pier

FIG. 39.

smaller pipes discharge into a large pipe. Double hubs and double hub fittings may be used on rain water leader and vent lines. Offsets having less than one-fifth pitch should not be permitted. The use of a drive ferrule is prohibited, and the use of combination lead ferrules should be permitted only when the calk joint can be made in the upright position. All waste and vent pipes should enter soil pipe by means of properly inserted fittings.

The drilling and tapping of soil, vent and waste pipes and house drains to receive waste and vent pipes of any description generally is strictly prohibited, and in no case is the use of saddles or bands permitted, without permission from the plumbing inspector.

Note.—All such saddles must be of efficient design and construction.

Whenver horizontal wrought or galvanized iron pipe connects with cast-iron soil, waste or vent pipes, tapped fittings or tap extension pieces should be used wherever practicable. No double hub or inverted calk joint should be permitted in soil and waste lines.

Section 17. *Lead Pipe Bends and Traps, Weight of.*—All pipe used for branch soil, waste, vent or flush pipes, including bends and traps, should be the best quality of drawn lead pipe, of not less weight per lineal foot than shown in Table 6.

TABLE 6

Inside diameter (inches)	Weight per foot
1	2 lb. 0 oz.
1¼	2 lb. 8 oz.
1½	3 lb. 8 oz.
2	4 lb. 0 oz.
3	6 lb. 0 oz.
4	8 lb 0 oz.

Section 18. *Brass Pipe, Fittings, Tubing, and Casting.*—All brass pipe used for soil, waste and vents, except fixtures, traps and overflows, should be of commercial iron pipe gage.

All brass fittings for soil, waste or vent pipes should be of a good quality of cast brass, having a thickness corresponding to brass pipe of the same diameter. The thickness of threaded ends must be equal to the thickness of the corresponding pipe size at the root of the thread.

All brass tubing used for fixtures, traps and overflows between wall or floor and fixtures should be of a good quality of brass and of a thickness at least equal to No. 18 Brown & Sharp gage.

All brass fittings used for fixtures, traps and overflows should be of a good quality of brass, free from sand holes, flaws or other defects, and of a uniform thickness equal to twice the thickness of the brass tubing. The thickness of the threaded ends should be equal to the thickness of the fitting at the root of the thread.

Soldering nipples should be of heavy cast brass, or of brass pipe of iron weight, thickness and size. When cast they should be of full bore and of not less than the weights given in the following table:

TABLE 7

Inside diameter, inches	Weights
1¼	0 lb. 6 oz.
1½	0 lb. 8 oz.
2	0 lb. 14 oz.
2½	1 lb. 6 oz.
3	2 lb. 6 oz.
4	3 lb. 8 oz.

Brass ferrules should be of a good quality of brass, composed of a mixture that will fuse readily with plumber's solder, free from sand holes, flaws or other defects, uniform in thickness, and at least 1½ in. long of a size and weight as per Table 8.

TABLE 8

Inside diameter, inches	Weights
1½	1 lb. 1 oz.
2	1 lb. 4 oz.
3	1 lb. 14 oz.
4	2 lb. 8 oz.
5	3 lb. 0 oz.
6	3 lb. 8 oz.

Traps and Clean-outs

Section 19. (*a*) *Traps.*—Each fixture, except those wasting as described in this section, should be separately trapped by a water seal trap, placed as close to the fixture as possible.

Every trap should be self-cleaning. No form of trap should be used which depends upon the action of movable parts for its seal. Nor should a trap be used which depends upon concealed interior partitions for its seal, unless such interior partitions are made of indestructible material. No trap should be used which in case of defect would allow the passage of sewer air. Grease traps with integral cast partitions of indestructible material may be used. Drum traps or their equivalent should be used whenever practicable under all bath tubs and shower baths

Traps for bath tubs, basins, sinks or other similar fixtures should be made of lead, brass or iron. (For depth of trap seals see Table 9 and for size see Table 1.) Each trap should have a water seal of not less than 2 in. Laundry trays, wash tubs, or similar fixtures may waste into a single trap. The outlet waste pipe and trap of three or four compartments should be at least 2 in. in diameter.

(*b*) *Trap Clean-outs.*—All traps placed between a floor and a ceiling, or in any other accessible place, should have a brass screw clean-out flush with the floor or accessible from under the floor.

TABLE 9.—DEPTH OF SEAL FOR COMMON TRAPS

Size of trap (inches)	1¼	1½	2	3	4	5	6
Depth of seal (inches)	2	2	2	2½	2½	2½	2½

DEPTH OF SEAL FOR DEEP SEAL TRAPS

Size of trap (inches)	1¼	1½	2	3	4	5	6
Depth of seal (inches)	4	4	4	5	5	5	5

All traps used in combination with fixtures which are readily accessible and removable need not be provided with a brass screw clean-out plug.

(c) *Setting of Traps.*—All traps should be rigidly supported and set true with respect to their water level, and be so located as to protect their seals. All that portion of the waste pipe of P trap extending to the point of venting is to be considered as a part of the trap, and the total fall between water level of the trap and vent should not exceed the inside diameter of the waste pipe (see Figs. 26, 27, 28, and 40, and Sect. 8 and 10).

(d) *Traps—Where Prohibited.*—Traps should not be placed at the foot of soil or waste pipe stacks, except where such a drain or sewer is used exclusively for conducting rain water or surface water to a house drain or sewer.

(e) *Traps or Rain Water Leaders.*—One trap may serve for one or more rain water leaders, providing no part of said pipe is used for a soil or waste pipe. When rain water leaders are carried up to the roof of a building they need not be provided with traps, unless such conductors terminate within 12 ft. of any door, window, ventilating hood or air intake. Conductor branches taken off a head of the main house trap on street side should be provided with traps properly located to guard against frost.

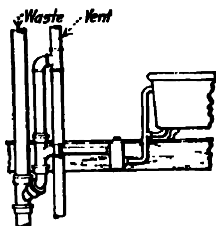


FIG. 40.—Method of connecting bath, showers, and similar fixtures.

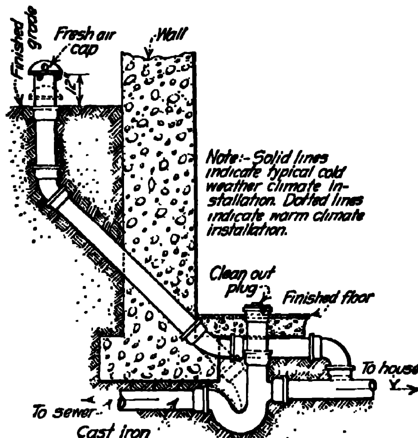


FIG. 41.—House trap and fresh air inlet.

(f) *Other Waste Connected to Water-closet Trap Prohibited.*—In no case should the waste from a bath tub or other fixture be connected with a water-closet trap.

(g) *Overflow Connections.*—Overflow pipes from fixtures in each case must be connected on the inlet side of the trap.

Section 20. (a) *Main House Trap.*—The house drain may be provided with a horizontal trap set level and placed immediately inside of foundation wall where sewer enters building. This trap should be provided with a handhole to which clean-out is connected.

Main house trap may be omitted (1) in building where the roof terminals of soil and vent stacks are favorably located, when plumbing is free from defects, fixture traps proper protected from siphonage, and the installation made in a durable and approved sanitary manner; (2) in new sewerage districts or districts practically free from main traps; and (3) with certain limitations, in sewerage districts where existing house drains are equipped with main trap.

When main traps are used they must be provided with a fresh air inlet on the house side of the trap (Figs. 20 and 41).

(b) *Fresh Air Inlets Where Main House Traps Are Used.*—There must be a fresh air inlet entering the house side at least 2 ft. from the water seal of the main trap. The inlet when exposed should be covered with a substantial fresh air cap or return bend. When located under a porch, a free circulation of air must be provided.

(c) *Location of.*—No fresh air inlet should be so placed that a cold air intake for a furnace or heater may draw air from the same, nor should it be open at a point less than 4 ft. from any door, window, or other air intake.

Section 21. *Back Flow Valves.*—Drain pipes from fixtures should be provided with adequate backwater valves when subject to back flow or backwater from sewer. Such backwater valves should be so placed as not to interfere with the flow or discharge of any conductor or rain water leader or other fixture, and be readily accessible for cleaning, and should be provided with a back vent pipe or fresh air inlet so arranged as to avoid a dead end.

Section 22. (*a*) *Clean-outs.*—Where main house traps are installed, cast-iron pipe should be extended from hand hole of trap to a point 2 in. above the surface of finished floor or grade. All clean-outs in house drains should be at least 4 in. in diameter (Figs. 20 and 41).

All additional clean-outs for main house drain should be extended where practicable to a point 2 in. above the surface of the finished floor or grade.

All other clean-outs should be of adequate size and located in such a manner as to serve the purpose for which they were intended, and all clean-outs should be so constructed as to make possible the entering of the drain with rod or wire.

(*b*) *Construction of Clean-outs.*—When solid brass screw caps for clean-outs are used, they should be at least ⅛-in. thick and provided with standard pipe thread and square or hexagonal head at least ¾ in. high. The ferrule when made of brass should be at least $^3/_{16}$ in. in thickness; and when made of iron the same weight per foot as extra heavy cast-iron soil pipe. The screw cap should have at least five threads of iron pipe size.

Note.—Clean-outs should be provided for all large troughs, pedestal and porcelain stall urinals at such points that all parts of waste may be reached conveniently with sewer rod or wire.

Joints and Connections

Section 23. (*a*) *Joints in Vitrified Pipe.*—Joints in vitrified pipe should be made with mortar composed of equal parts of hydraulic or Portland cement and sharp clean sand, thoroughly mixed dry, with enough water added to give the proper consistency. The joints must be pointed carefully on the outside, and the pipe left clear and smooth on the inside by drawing through it a swab or scraper.

(*b*) *Vitrified and Iron Pipe.*—Underground joints between vitrified and iron pipe should be made the above required for vitrified pipe.

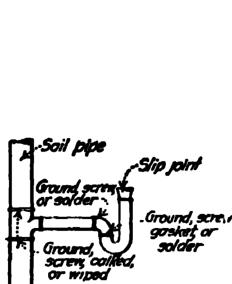


FIG. 42.—Permissible trap joints and connections.

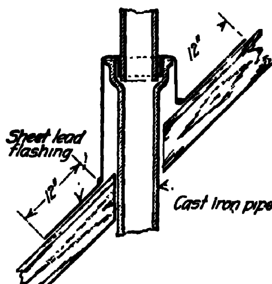


FIG. 43.—Roof flashing for cast-iron pipe.

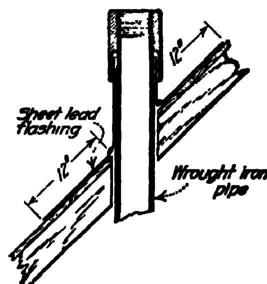


FIG. 44.—Roof flashing for wrought-iron pipe.

(*c*) *Cast-iron Pipe.*—All joints in cast-iron pipe should be made by first inserting a roll of hemp, oakum or jute and thoroughly calking it in place, and then following with pure molten lead well calked, not less than 1 in. deep, lead to be brought to top of hub and faced. No paint, varnish or putty should be allowed in the joints until they have been tested.

(*d*) *Wrought Iron and Brass.*—Joints in galvanized iron or brass pipe should be standard screw joints, and all burs or cuttings should be removed. All screw joints should be made with white or red lead, mineral paint, red lead and varnish or other approved compounds.

(*e*) *Wrought Iron or Brass and Cast Iron.*—Connections between wrought iron or brass and cast iron should be either a calked joint or a screw joint.

The following table shows the number of threads per inch on standard wrought iron or full weight steel pipe:

Size of pipe (inches)	Number of threads to the inch
⅛	27
¼ and ⅜	18
½ and ¾	14
1 to 2	11½
3 to 10	8

(*f*) *Joints in Lead Pipe.*—Joints in lead pipe or between lead, brass or copper pipes should in all cases be wiped joints except solder brazed or sweated joints on brass reamed concave bushings in connection with exposed brass or lead traps shown in Figs. 27 and 42.

(*g*) *Wrought-iron Pipe Connections.*—Connections between lead and cast or wrought-iron pipes should be made with a calked joint, a soldering nipple or threaded joint. Wrought-iron pipe connections should be made with a right and left coupling, flanged union with durable gasket, a ground faced union or an extra heavy running thread

with lock nut made tight with wicking and red or white lead, and be asphaltum coated upon completion. All unions used on the sewer side of traps should be ground faced. No slip-joint connection should be allowed on the sewer side of the trap (Fig. 12).

Section 24. (a) *Roof Joints.*—The joint at the roof should be made water-tight by the use of proper sheet copper or lead plate (Figs. 21, 13, 11 and 45).

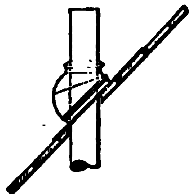


Fig. 45.—Roof flange.

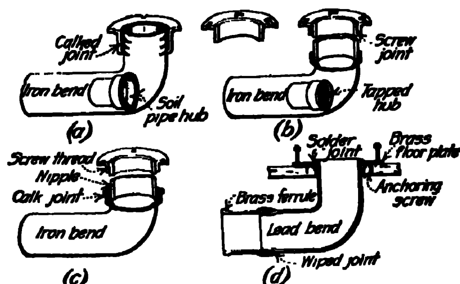


Fig. 46.—Closet and similar fixture bends.

(b) *Roof Flashing.*—Sheet lead for roof flashing should weigh not less than 3 lb. per sq. ft. and should extend not less than 6 in. from the pipe. Other flashings of substantial material are permitted.

Note.—Roof flashings of durable material designed and constructed so that an adequate air space is provided between the pipe and flashing are recommended. The term "substantial material" as used in this section is intended to mean 3 lb. sheet lead, or copper, brass or galvanized iron of adequate weight and construction.

Section 25. *Earthenware with Metal Floor Connections.*—The connections between soil pipe and fixtures with combined earthenware, vitreous china or enameled iron may be made with a solid brass floor plate, not less than $\frac{3}{16}$ in. thick, soldered, screwed or calked to bend or pipe, securely anchored to the floor and bolted to trap flange (Fig. 16).

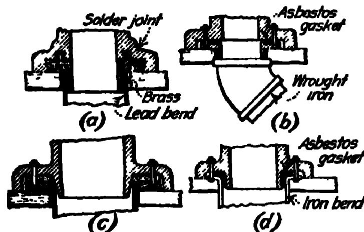


Fig. 47.—Methods of making earthenware to metal floor connection.

Joints should be made air-tight with an adequate asbestos graphite ring or asbestos gasket washer. To insure the tightness of this joint a paste of red or white lead or other equal compound of the consistency of putty, should be used. Add sufficient putty or whiting to the read lead to make the proper mixture (Fig. 17). Various patented joints of approved make are usually permissible.

Section 26. *Water and Air-tight Joints.*—All joints and connections mentioned under this title should be of substantial construction and be made water-tight and air-tight.

Section 27. *Connections to Lead Closet or Similar Bend.*—It is recommended that no waste pipes conveying hot water be branched into lead bends receiving the discharge of water-closets or other similar fixtures, except that for economical and practical installation reasons it may be permitted in cases where new fixtures are added to old installations (Fig. 46).

Surface and Rain Water Connections

Section 28. (a) *Rain-Water Leaders Not to Connect to Sanitary Sewer.*—Roof leaders or down-spout wastes and surface and ground water drains should be connected wherever possible with a storm sewer; but they should not be connected to house sewers which discharge into sanitary sewers.

(b) *Inside Leaders.*—All roof leaders, when placed within the walls of any building, in an interior court, or in a ventilating or pipe shaft, should be made and placed as specified for soil, waste and vent pipes.

(c) *Connections with Rain-Water Leaders—When Prohibited.*—Rain water leaders should not be used as soil, waste or vent pipes; nor should any soil, waste or vent pipes be used as rain water leaders.

(d) *Defective Rain-Water Leaders.*—When an existing rain water leader within the walls of any building becomes defective, such leader should be replaced by one which conforms to the sanitary requirements.

(e) *Rain-Water Leaders When Connected to Drains.*—When rain water leaders are connected to house drains within the building, the horizontal part extending 2 ft. inside the basement wall and the vertical portion outside the building wall should terminate with the hub at grade line, and should be made of cast iron of same weight and durability as provided for house drains (see Fig. 18).

(f) *Roof Terminal Connections.*—Connections between gutters, troughs, roof areas and rain water leaders inside the building should be made of durable material (see Section 19e). *Note.*—The term "durable" material as used in this section means a brass ferrule, a brass soldering nipple, extra light lead pipe, 12 oz. copper, No. 18 gage brass or cast iron receivers properly connected with calk or screw joint, or the equivalent of any of those mentioned above.

(g) *Rain-Water Drains to Curb.*—Where no sewer is accessible, or where rain water is prohibited from entering the sanitary sewer, surface inlets and rain water conductors should be drained separately to the curb line where practicable by drain pipes not less than 4 in. in diameter, and discharged into the public gutter, unless permitted to drain elsewhere.

Miscellaneous Provisions

Section 29. *Three-inch Soil Stack.*—Where a 3-in. soil pipe stack is in place, or where it is wholly impracticable to use a 4-in. soil pipe for water-closets, a 3-in. soil pipe may be used for vertical stacks which should conform in construction with Fig. 49, also Table 1.

Section 30. *Rural Residence. Installation.*—Where plumbing is to be installed in a small rural residence with main sewer draining into a residential septic tank, it may be done in accordance with Figs. 29 and 50. The piping must, however, be so designed that every fixture trap is protected from siphonage, and air circulation assured by means of a fresh air inlet on main drain and a vent where necessary.

Section 31. *Hot Water and Steam Wastes.*—All exhaust, blow-off, sediment or drip pipe connections from a steam boiler or any other hot water discharge should not be connected to any house sewer or drain without first being cooled below a temperature of 140 deg. F. in a suitable tank, catch basin or other cooling device; when necessary such installation must be provided with an adequate local vent or relief pipe, extending to the outer air.

Note —The capacity of the catch basis or other cooling device and the relief pipe depends upon the steam pressure carried, size of the boiler, and volume discharged.

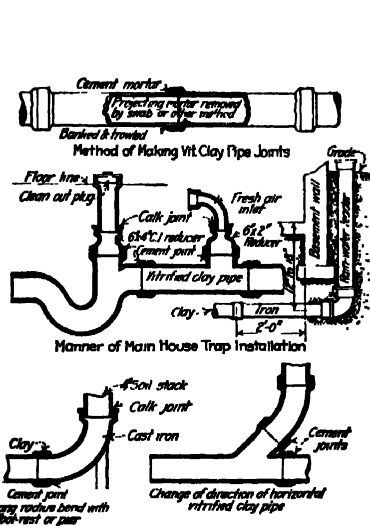


Fig. 48.—Methods in connection with the installation of vitrif.ed clay house drains.

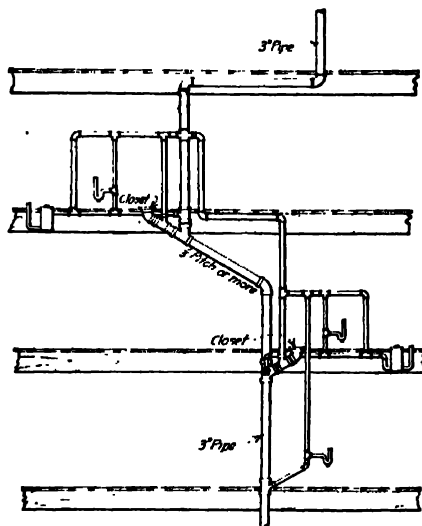


Fig. 49.—Method of installing closets on 3-in. pipe.

Section 32. *Terminals.*—The roof terminals of all vent pipes should be extended at least 3 ft. above any, door, window, scuttle, air shaft or other opening used for ventilation when located at a distance less than 12 ft. from such terminal (Figs. 22 and 23). When it is necessary to extend the roof terminals of soil, waste or vent pipes more than 3 ft. above the roof, they should have an adequate frost-proof covering.

Whenever a new building is erected higher than an adjacent existing building, the owner of the new building should not locate windows within 12 ft. of an existing vent stack on the lower building, unless the owner of such new building defrays the expenses or makes, himself, the alterations necessary to conform with this requirement.

Section 33. *Waste Pipes for Acid Tanks.*—The waste pipes and traps for acid tanks, sinks and other receptacles receiving the discharge of acids in chemical laboratories, electrotyping, lithographing and other similar establishments must be made of extra heavy cast iron, coated inside and out with tar and asphaltum, extra heavy lead pipe, or lead-lined iron pipe of adequate durability. The waste pipes may be of vitrified clay when placed outside the building, or when serving within the building as a local conveyor between acid tank, dilution tank, or other receiving basin.

Catch Basins, Sumps and Ejectors

Section 34. (*a*) *Grease Catch Basins.*—All grease catch basins should be constructed in a water-tight and substantial manner of brick, cement, concrete, iron or vitrified clay pipe. The outlet should be provided with a 4-in. inverted bend and clean-out, should be submerged at least 8 in., and should be placed in the wall of the basin not less than 2 ft. 6 in. above the bottom. The basin should have an air-tight stone, cement or cast-iron cover.

(*b*) *Where Used.*—Grease catch basins of adequate capacity are usually required wherever kitchen or other greasy wastes from hotels, restaurants, club houses, public institutions or similar places are discharged into the sewer. The capacity of the basin should be at least twice that of the volume of waste discharged during any 1 hour. In many localities grease catch basins may be omitted from the plumbing system of a private residence.

Note.—Grease traps of the water-cooled type properly designed, constructed and installed and of adequate capacity usually are permitted.

(c) *Where Located*—Whenever possible, grease catch basins should be installed just outside the wall of the building, and as near as possible to the kitchen or other sink. Where they are installed on the inside of buildings, they should be made of cast iron or reinforced concrete, with air-tight iron cover. Concrete catch basins should have a metal ring embedded in the concrete to which cover may be bolted (Fig. 51).

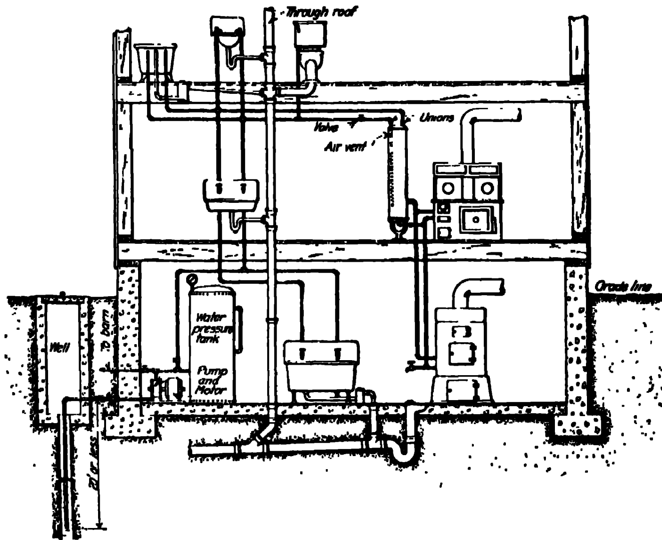


FIG. 50.—Rural home comforts.

Section 35. *Yard Catch Basins.*—A yard catch basin should be constructed in the same general manner as provided for grease catch basins, except that they should be at least 20 in in diameter, and in cold climates the outlet should, where possible, be at least 4 ft. below the surface of the ground. The basin should have a cover of stone or heavy cast iron with strainer flush with the surrounding ground.

A yard catch basin may be installed to receive surface drainage or discharge from pump, yard, hydrant or other outside waste.

Section 36. *Stable Catch Basins.*—When liquid wastes from barns, stables, manure pits and stable yards are permitted to enter the public sewer system, they should be intercepted by a properly trapped catch basin of suitable design.

Conductors or down-spouts when permitted in a sewerage system may be connected with such stable or barn catch basins to act as local vents.

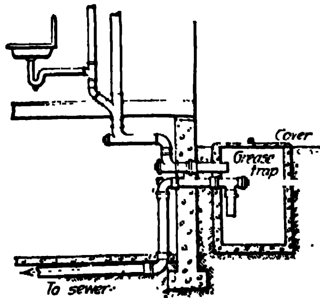


FIG. 51.—Method of connecting sink waste to grease catch basin.

Section 37. *Garage Catch Basins.*—Garage drains should be intercepted before entering the sewer by a suitable catch basin properly trapped. A 4-in. conductor pipe when permitted to connect with house drainage or sewerage system may be connected to this catch basin to act as a local vent. In the absence of the latter, a 4-in. fresh air inlet from the outer air or a local vent through the roof is recommended. Some types of commercial "garage intercepting basins" are so designed that they may be recommended. Size of basin, method of installation and proper connection are important factors.

It is recommended that garage drains discharge into yard catch basins constructed in the manner provided in Sect. 35.

Note.—Grease, yard, stable and garage catch basins and other similar receptacles must be kept clean and sanitary. The sediment collected in the same should be removed often enough to prevent obstruction of the drainage pipes.

Section 38. (a) *Ejectors—When Required.*—In all buildings in which the whole or a part of the drainage and plumbing system lies below the flow of the main sewer, the sewage or house wastes should be lifted by artificial means and discharged into the main sewer.

(b) *Sumps and Receiving Tanks.*—All house drains discharging below the floor line of the main sewer should be connected to a sump of adequate capacity with air-tight cover. It should be so located as to receive all such drainage by gravity and be vented with an adequate vent pipe.

Floor Drains and Fixture Wastes

Section 39. *Basement Floor Drains.*—Cellar or basement floor drains should not be permitted unless they connect with a deep seal trap so constructed that it can be cleaned readily, and under proper conditions sewer air excluded (see Section 106).

When subject to back flow, such drains should be equipped also with an adequate backwater valve (see Sect. 21 and 10).

Note.—When possible ice-box drains, bubblers and similar wastes should be connected with the floor drain so as to maintain a permanent water seal (Fig. 52).

Section 40. *Subsoil Receiver.*—The discharge of drain tile from footings of buildings should be collected in a subsoil receiver or trap, of adequate capacity, having a watertight cover securely bolted or screwed on. This cover should be at least 2 in. above the basement floor (Fig. 53).

Note.—Subsoil drainage frequently carries sand from surrounding soil. For this reason care should be taken that the tile is not so installed that it will undermine the footings of foundation walls. When subsoil drains are connected to the sewerage system subject to back flow, such drains must be equipped with an adequate backwater valve.

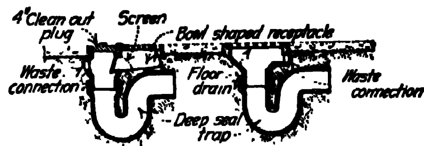


Fig. 52.—Typical floor drains.

Section 41. *Wastes from Laundries and Similar Establishments.*—Waste pipes in dye houses, breweries, bottling works, dairies, laundries, and similar establishments where much water is used may discharge directly upon a non-absorbent floor, provided with an adequate number of floor drains, which drains should be connected to the house or yard catch basin by means of cast iron or vitrified pipe.

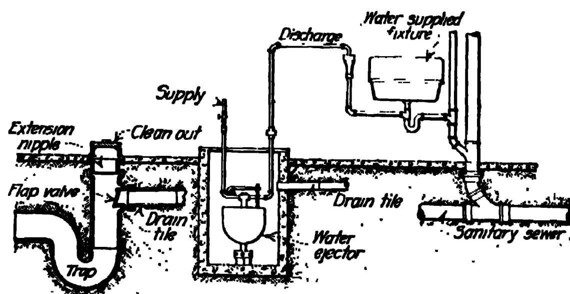


Fig. 53.—Method of connecting subsoil or tile drains with sanitary sewer.

Floor drains located above basement floor should be considered as a plumbing fixture and should be of adequate size (Figs. 54 and 55).

Note.—The wastes coming from laundries and similar industries located above the basement floor may, as a result of the production of soapsuds, create conditions that will affect the flow of wastes coming from other fixtures on the same soil or waste line. An independent line or lines, as the case may require, should therefore be provided.

Section 42. *Soda Fountain Wastes.* Bar, soda fountain and similar wastes may be installed in accordance with one of the methods shown in Fig. 56.

The trap, waste and vent pipes may be located at either side of the bar or at any convenient point at the side of the bar.

Note.—It is recommended that the washing compartments be provided with standing waste and overflow pipe, and that a continuous flow of fresh water be maintained while the bar or fountain is in use.

Section 43. *Ice House and Storage Drains.*—The floor drains in ice house and refrigerator rooms, markets, slaughter-houses, storage rooms for provisions, or any room where ice is stored or used should be of adequate size, properly trapped, and when necessary discharge into a catch basin.

Section 44. *Refrigerator Wastes.*—The waste pipe from a refrigerator, ice box or trap, or any receptacle in which provisions are stored should not connect directly with any drain, soil or waste pipes. Such waste pipes should be so arranged that they may be flushed properly (Fig. 57).

Section 45. *Areas and Court Drains.*—When permitted to connect to the sanitary or house drainage system, the various drains from small yards, areas and courts may be connected together and their contents discharged into a yard catch basin, an adequate basement floor drain or a deep seal trap, so located that it is readily accessible for cleaning and is protected from frost. The surface opening of the drain to catch basin must be provided with an adequate strainer, and where necessary with a back flow valve.

Section 46. *Elevator Connections.*—All hydraulic elevators, lifts and motors in order to prevent back pressure in any sewer drain, soil or waste pipe, should discharge into a tank of adequate capacity. Such tanks should have an adequate deep seal trap or inverted bends and where necessary a back-water valve (also see Sect. 10 and 21).

Section 47. *Bubbler Waste—How to Drain.*—Waste pipes from bubblers may discharge into an open fixture, trapped funnel or floor drain. Such waste pipes, however, should be trapped to preclude their use as a local vent for cellar, etc.

When bubblers are connected directly to soil, waste or drain pipes, they should be trapped and vented properly (Fig. 58).

Section 48. *Dental Cuspidors.*—Dental cuspidors when connected to a waste pipe must be effectively trapped and may be adequately vented as shown in Fig. 59.

The length of the horizontal waste pipe between the vent pipe and trap must not exceed 15 ft. The total fall of the horizontal waste pipe between trap and vent should not exceed the inside diameter of said waste pipe.

Section 49. *Cistern Overflow*.—Overflow pipe from cisterns should not connect directly with any house sewer, but should discharge into an open fixture, catch basin or floor drain.

Note.—Overflow pipes from cisterns should not discharge, however, into sanitary sewers intended for domestic use only.

Section 50. *Overflow Pipes*.—The discharge of waste pipes from pumps, water motors, overflow pipes from water supply tanks, expansion tanks and drip pans should be provided for in the same manner as for refrigerator wastes.

Plumbing Fixtures

Section 51. (*a*) *Fixtures—Water-closets*.—All water-closets should be made of porcelain or vitreous chinaware. The bowl and trap should be of the combined pattern in one piece, and should hold a sufficient quantity of water and be of such shape and form that no fecal matter will collect on the surface of the bowl. All water-closets should be equipped with adequate flushing rims, so as to flush and scour the bowl properly when discharged.

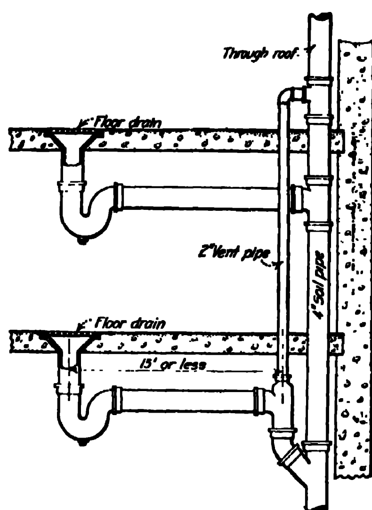


Fig. 54.—Method of connectin-- similar floor drai

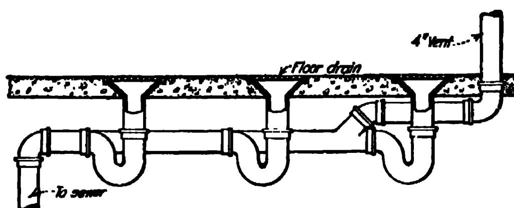


Fig. 55.—Method of connecting large floor drains.

Note.—For public buildings, the bowl should be of the heavy pattern, large throatway, of siphonic action type.

(*b*) *Frost-proof Closets, When Permitted*.—Frost-proof closets should be installed only in compartments which have no direct connection with any building used for human habitation. The soil pipe between the hopper and the trap must be of cast iron, 4 in. in diameter, and free from offsets. This type of closet should be used only in buildings subject to extreme frost conditions. When frost-proof closets are installed, the bowl must be of vitreous chinaware or iron enameled inside and outside, of the flush rim pattern, provided with an adequate tank, and automatically drained to guard the fixtures and piping against frost.

Note.—The installation and use of the above type of fixture should be discouraged as much as possible. Under the most favorable conditions little can be said for this closet from a practical and sanitary standpoint.

Section 52. *Urinals*.—Urinals should be made of material impervious to moisture, and of such design, materials, and construction that they may be properly flushed and kept in a sanitary condition. If cast iron is used in the construction of urinals, it must be enameled on the inside of the trough or bowl and coated with a durable paint or enameled on the outside. Trough and lip urinals should have a floor drain placed below the urinal and the floor should be graded toward the drain.

Note.—Individual urinals rising from the floor, with the floor pitched toward the urinal, made of porcelain or vitreous chinaware, and equipped with an effective automatic, or equivalent, flushing device and adequate local vent, are recommended.

Section 53. *Bath tubs, Sinks and Laundry Tubs*.—Bath tubs should be made of earthern ware, vitreous chinaware, enameled iron ware or other impervious material. Sinks and laundry tubs may be made of other materials where conditions make it necessary. They should be equipped with adequate traps and sanitary waste stoppers.

(*a*) *Flush Tanks*.—All flush tanks or flushometer valves should have a flushing capacity of not less than 3 gal. for water-closets and not less than one gallon for urinals, and be so installed that they are protected against frost, tampering, etc.

(*b*) *Drinking Water*.—Systems and installations supplying drinking water shall be of durable material and so constructed and installed that pollution or contamination is not reasonably possible.

(*c*) *Water Supply to Fixtures*.—All water-closets, urinals or other plumbing fixtures should be provided with a sufficient supply of water for flushing them in a sanitary manner.

(*d*) *Capacity for Flushing*.—All systems, installations and pipes supplying water for the flushing of closets, urinals or similar fixtures shall be of sufficient capacity and size to provide adequate volume and pressure.

(*e*) *Contamination from Fixture Connection*.—The water supply to any fixture shall be so placed as reasonably to preclude the possibility of the contents of such fixtures being syphoned or drained into the water supply pipes.

Section 54. *Location of Fixtures*.—Toilet rooms and bathrooms should have at least one outside window or be provided with local vent pipes or air shafts so as to insure at least four changes of air per hour. Local vents or air shafts for toilet rooms shall not be connected with the plumbing system and must be so installed as to provide adequate ventilation.

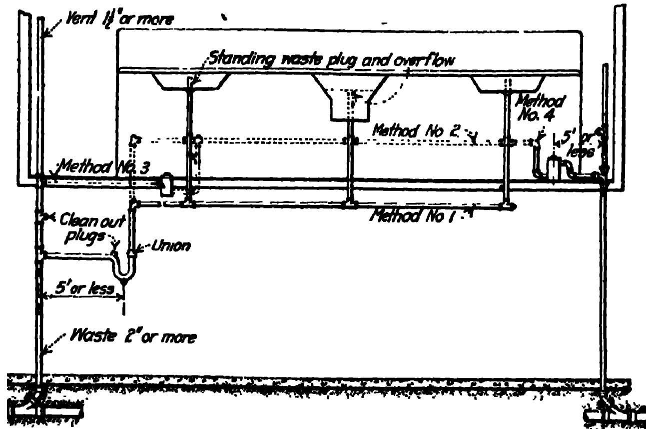


FIG. 56.—Recommended methods of connecting soda fountain wastes.

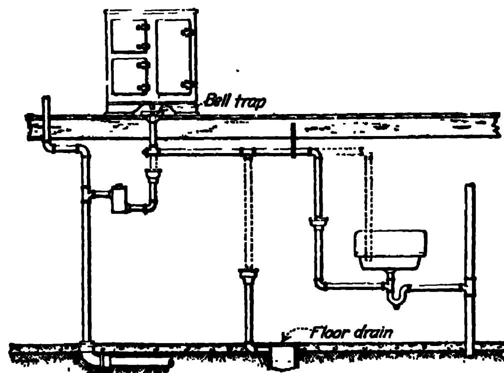


FIG. 57.—Methods of connecting refrigerator wastes.

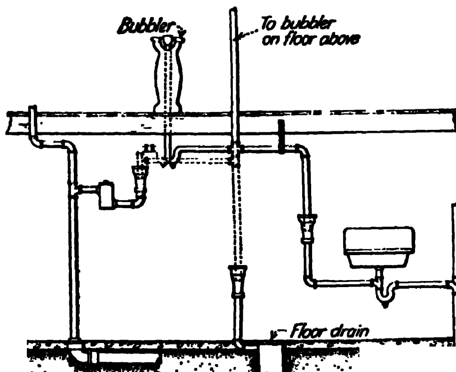


FIG. 58.—Three methods of connecting bubbler wastes.

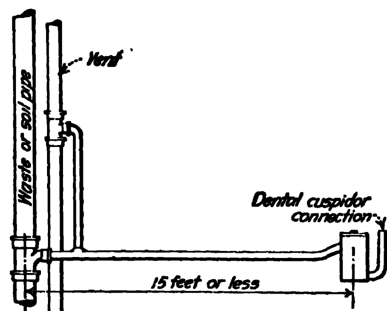


FIG. 59.—Dental cuspidor installation.

Open Plumbing.—All plumbing fixtures should be installed or set free and open from all enclosing work. Where practicable all pipes from fixtures, except fixtures with integral traps rising from the floor, should be run to the wall.

Note.—It is essential that all plumbing fixtures for public building service be of high grade, and of such design and construction and so installed as to be practically fool-proof.

Piping.—Wherever practicable, the piping, tanks, flushing devices, traps, etc., should be installed exposed in a utility chamber and so arranged that they are accessible for the removal of stoppages (see chapter on "Public Comfort Stations" in Part I, Sect. 1).

Protection against Frost.—All water-closets and urinals and the pipes connecting therewith should be protected properly against frost, either by a suitable insulating covering or by an efficient heating apparatus, or in some other approved method, so that the facilities will be in proper condition for use at all times.

Note.—Toilets should be adequately heated in cold water. Heating equipment should be arranged to permit cleaning of floors and walls.

Where Water and Sewerage Systems are Available.—Each water-closet and urinal and each lavatory or sink located in a public or private building should be connected properly with sewerage and water systems where possible.

Where Water and Sewerage Systems are Not Available.—In localities lacking public systems of water and sewerage, the disposal of human wastes may be accomplished as follows:

1. By an efficient water system of the "compressed air storage" or "air pressure delivery" type and a proper sewerage treatment tank and disposal units, as existing conditions may require.

2. By outdoor privies or other toilet conveniences permitted by federal, state or local authorities, when local conditions make it impractical to install a water supply and sewage disposal system.

Repairs and Reconstruction

Section 55. (*a*) *Old Materials Re-used.*— All fixtures, soil, waste and vent pipes removed from an old building, if found to be in good condition, may under the requirements of most ordinances be used in the same building or in another building. In some instances written consent is required of the owner of the building in which such fixtures are to be installed.

(*b*) *Old House Drains.*—Old house drains may be used in connection with new buildings or new plumbing only when they are found on examination or test to conform to the requirements governing for new sewers and drains. If the old work is found defective, the local or state inspector usually notifies the owner of the changes necessary to make it conform to the requirements of the ordinance.

(*c*) *Fixtures Replaced.*—When an old or defective fixture is removed, to be replaced by a new one, and no other fixture or piping is to be added or remodeled, it may not be necessary to reconstruct the soil, waste or vent piping to make it conform to rules governing, unless the same is in a defective condition. In such cases, if found necessary, the fixtures should be provided with efficient deep seal traps or deep seal resealing traps of the self-scouring centrifugal type.

(*d*) *Reconstruction.*—When old or defective plumbing is to be remodeled, additional fixtures installed or the whole plumbing system moved to another part of the building, then the remodeled system should be made to conform reasonably to the regulations in force.

(*e*) *Repairs.*—All repairs to fixtures or piping should be made in a substantial, sanitary and workmanlike manner.

(*f*) *Insanitary Installations.*—No fixtures or installations should be maintained which are insanitary or of improper design.

Inspections and Tests

Section 56. (*a*) *Local Inspections.*—All piping of a drainage or plumbing system in cities having local plumbing inspectors (except in case of repairs as specified in subsection *m*) should be tested by the plumber in charge in the manner herein provided, in the presence of the local inspector of plumbing or his authorized deputies. Where no state or local inspector is provided, the engineer, architect, owner, or a competent representative should arrange to witness all tests prescribed

(*b*) *Materials and Labor.*—The material and labor for tests should be furnished by the plumber in charge.

(*c*) *House Drain Tests.*—The entire house drain with all its branches, receptacles and connections, should be brought so far as practicable to the surface or grade of the basement floor and tested with water or air. Upon being found free from defects and leaking joints, the test may be considered satisfactory.

(*d*) *Stable and Garage Tests.*—If a stable, garage or any part thereof is used for human habitation, or is so constructed that it may be used as such, the same tests should be made as for an ordinary dwelling.

(*e*) *Rain Leader Tests.*—Rain water leaders and their roof connections where they are permitted within the walls of any building, and such branches as connect with the house drain 3 ft. beyond the basement wall, should be tested with water or air.

(*f*) *Covering of Work.*—No part of any plumbing or drainage system should be covered until it has been inspected, tested, and approved. If any part is covered before being tested and approved, it should be uncovered at the direction of the inspector.

(*g*) *Final Inspection.*—When the plumbing or drainage system is completed and fixtures are installed, the final inspection should be made; and no such plumbing or drainage system should be used until it has been inspected and approved, unless special permission is given by the proper authorities for its temporary use.

(*h*) *Inspection for Changes or Alterations.*—When additional fixtures are installed or the style or location of any fixture is changed or when changes are made in the piping system, the work should be inspected.

(*i*) *Soils, Waste and Vent Tests.*—Soil, waste and vent pipes, rain water leaders and all work known as "roughing in" and "underfloor work" between the house drain connections to points above the finished floors and beyond the finished face of walls and partitions should be tested.

(*j*) *Water and Air Test.*—The water test should be applied by closing all openings in the pipes with proper testing plugs to the highest opening above the roof, and completely filling the system with water, or an air test with pressure of at least 5 lb. should be used. If the pipes are found free from defects and leaking joints, the test may be considered complete and satisfactory. Buildings five or more stories high may be tested in sections as directed by the proper official.

(*k*) *Air Test.*—When water is not available, or when there is danger of freezing, the air test, with a pressure of at least 5 lb. may be used.

(*l*) *Smoke Test.*—The smoke test should be used in testing the sanitary condition of the drainage or plumbing system of all buildings where there is reason to believe it has become dangerous or defective on account of settlement of the building, abuse, accident or other cause.

The smoke machine should be connected to any suitable opening or outlet in the system. When the system is filled completely with dense pungent smoke, and the openings emit smoke, they should be closed, and an air pressure equivalent to a 1-in. water column applied, and left standing at least 10 min. If there is no leakage or forcing of trap seals, the system may be considered air- and gas-tight. Nothing coming under this provision should be construed, however, as prohibiting the removal of any clean-out or the unsealing of a trap to ascertain if the smoke has reached all parts of the system.

(*m*) *Tests for Repairs.*—Inspections may be made, but tests should not be required, after the repairing or replacing of any old fixture, faucet or valve by a new one to be used for the same purpose, forcing out stoppages, repairing leaks or relieving frozen pipes and fittings. Such repairs or alterations may not be construed to include cases where new vertical or horizontal lines of soil, waste, vent or interior rain water leaders are used or their relative locations changed. In a building condemned by the proper authorities because of insanitary conditions of house drainage or plumbing, tests and inspections should be made as for new buildings. In such cases repairs or alterations should be made which are necessary to make the plumbing sanitary.

Note.—No test nor inspection should be required where a house drainage and plumbing system or part thereof is set up for exhibition purposes; nor should a test be required (although inspection may be made) where the plumbing is placed in an outhouse, stable or detached building used exclusively for such purpose.

(*n*) *Preparations for Inspection.*—When work is ready for inspection the plumber in charge, or in case none is employed, the owner, should make such arrangements as will enable the inspector to reach all parts of the building readily, should have present the proper apparatus and appliances for making the tests, and should furnish such assistance as may be necessary in making proper inspection.

(*o*) *Notice for Inspection* The plumber in charge, or the owner of the property in case no plumber is employed, should notify the inspector in person, by telephone or in writing when the work is ready for inspection. If the inspection is not made within a reasonable time after the notice is given, the plumber in charge, or the owner, may proceed with the work, or, where valid reasons exist, he may defer, or decline to make, the inspection.

Section 57. *Defects in Materials* —If tests or inspection disclose defective material, leakage, or unworkmanlike construction, which does not conform to the sanitary requirements and which is condemned by the inspector, the same should be removed and replaced within three days, and when necessary retested

The presence of any foreign substance, other than that provided for in the rules governing, about a joint or any part of a plumbing or drainage system should be sufficient cause for condemning such joint or part of the system. Any split fittings, hubs or defective materials which do not conform to the requirements, and which have been condemned by the proper authority, should be removed from the work and not used again.

Toilet Room Requirements for Public Buildings and Places of Employment

Note.—"Approval by the proper authorities," as used in the following sections, is intended to mean approval (1) by State or federal authorities in conformity with laws, rules and regulations governing, or (2) by the city plumbing inspector, building department, or health department (as the case may be), where such official or department acting under the provisions of a city ordinance issues an order or permit for the work in question.

Section 58. *Toilet Rooms Required.*—Every place of employment and every public building should have adequate toilet rooms, completely enclosed, and so arranged as to insure privacy; except that in foundries, rolling mills, blast furnaces, tanneries, and similar buildings, partitions enclosing toilets should be at least 7 ft. high, but need not in all cases be carried to the ceiling nor enclosed at the top, provided such ceiling is at least 15 ft. high, and provided such toilets are located in rooms which females are not allowed to enter.

Note.—Under some regulations the foregoing exemptions are permissible even though the ceiling is lower than 15 ft., if local ventilation through the closet bowl and urinals is supplied in an approved manner. Much time may be saved for employes, especially in factories, by the placing of toilet rooms on each occupied floor.

Section 59. *Toilet Rooms for the Two Sexes.*—Where the two sexes are accommodated, separate toilet rooms must be provided, except

(1) In apartment houses and private homes;

(2) If approved in writing by the proper authorities in buildings accommodating not more than five persons of both sexes, provided the door of such toilet room is kept locked and the key kept in a place accessible to all such persons. But whenever the number of such persons exceeds five, separate toilet rooms should be provided.

Entrances to toilet rooms for the two sexes should be properly separated by screens or otherwise and should, wherever possible, be at least 20 ft. apart.

Section 60. *Sex Designated.*—Wherever women are employed or accommodated, each toilet room should be distinctly marked with regard to the sex which uses it, and no person should be allowed to use a toilet room assigned to the other sex, except as provided in Section 59.

Section 61. *Location, Light, Ventilation.*—Every toilet or bath room should be so located as to open to the outside light and air by windows or skylight openings directly upon a street, alley, court, or vent shaft, except as

hereinafter provided. Every such vent shaft should have a horizontal area of at least 1 sq. ft. for each water-closet or urinal adjacent thereto, but the least dimension of such shaft, if one-story high, should not be less than 3 ft.; if two stories high, not less than 4 ft.; and 1 ft. additional for each additional story.

The glass area for a toilet room containing one closet or urinal should be at least 4 sq. ft., with 2 sq. ft. additional for each additional closet or urinal.

In addition to the windows herein required, each toilet room which contains more than three fixtures (closets and urinals) should have a vent flue of incombustible material, vertical or nearly so, running through the roof, with proper cap or hood, and of not less than the following size:

Four fixtures	8-in. pipe
Five or six fixtures	10-in. pipe
Seven to ten fixtures	12-in. pipe

But if the windows or skylights can not be opened, then vent pipes should be provided as specified in Sect. 62.

No toilet room should have a movable window or ventilator opening on any elevator shaft or any court which contains windows of sleeping or living rooms above; except that a toilet room containing not more than two closets may have a movable window on such court if the room has a vent flue running above the roof.

Section 62. *Location without Outside Windows—When Permissible.*—If a location with outside windows is impracticable, a different location may be permitted, as follows:

(1) For a toilet used by not more than three persons, without special permit.

(2) For a toilet in a new building, used by more than three persons, only upon written approval.

(3) For a new toilet room in an existing building, used by more than three persons, only with the written approval of the proper authorities. (Such approval usually is granted only where a location with outside windows is not reasonably possible.)

Where a toilet room without outside windows is permitted, it should have a fixed window or windows to an adjoining room, with glass areas as provided above, arranged so as to furnish as much light as possible. Frosted or other translucent glass should be used when necessary for privacy. In no case should the floor be made of wood. A vent flue of incombustible material should be provided, vertical or nearly so, running through the roof, with proper cap or hood, and of not less than the following size:

One fixture (closet or urinal)	6-in. pipe
Two fixtures	8-in. pipe
Three fixtures	10-in. pipe
Four or five fixtures	12-in. pipe
Six or seven fixtures	14-in. pipe
Eight to ten fixtures	16-in. pipe

Notes.—(1) Glass are 50 % greater than required is recommended.

2. An air inlet is recommended if it can be made sound-proof.

3. A fan in the flue may be required if necessary for proper ventilation. If there is no fan a steam coil, or even an electric light at the bottom of the flue, will help to provide circulation. Where a metal vent pipe extends above the roof, a double pipe or other insulation against cold, is recommended.

4. Closets provided with a local vent are recommended and may be required in some cases before approval is granted.

Section 63. *Existing Toilet Rooms—Ventilation.*—Every toilet room heretofore installed, which is not adequately ventilated by outside windows or skylight, should be provided with a vent flue of size as specified in Section 65, in which flue a fan is required if necessary for proper ventilation.

Every such toilet room which cannot be kept sanitary should be moved so as to be open to outside light and air.

Section 64. *Artificial Light.*—Every toilet room (except in a private apartment) should be artificially lighted during the entire period that the building is occupied, wherever and whenever adequate natural light is not available, so that all parts of the room are easily visible.

Section 65. *Size.*—Every toilet room should have at least 10 sq. ft. of floor area, and at least 100 cu. ft. of air space, for each water-closet and each urinal.

Section 66. *Floor.*—The floor and base of every toilet room should be constructed of material (other than wood) which does not readily absorb moisture and which can be easily cleaned; except that wood floors may be used.

1. In private apartments.

2. If approved in writing by the proper authorities, in existing buildings where there is a wood floor in good condition and where such toilet will be used by not more than five persons; provided further that such room must have an outside window or skylight.

Section 67. *Walls and Ceilings.*—The walls and ceiling of every toilet room should be completely covered with smooth cement or gypsum plaster, glazed brick or tile, galvanized or enameled metal, or other smooth, non-absorbent material. For small toilet rooms receiving light use, wood may be used if well covered with two coats of body paint and one coat of enamel paint or spar varnish, kept clean and in good repair. But wood should not be used for partitions between toilet rooms, nor for partitions which separate a toilet room from any room used by the opposite sex. All such partitions should be as nearly sound proof as possible.

Note.—Walls and partitions should be of light color to increase illumination and facilitate cleaning.

In large rooms a hose connection and floor drain should be provided.

Section 68. *Partitions between Fixtures.*—Adjoining water-closets should be separated by partitions. Each individual urinal or urinal trough should be provided with a partition at each end and at the back, to give privacy. Where individual urinals are arranged in batteries, a partition should be placed at each end and at the back of the battery. A space of 6 to 12 in. should be left between the floor and the bottom of each partition. The top of the partition should be from 5½ to 7 ft. above the floor. Doors, of the same height as required for partitions, should be provided for water-closet compartments used by females. Doors at least 24 in. high, with the center of the door about 3 ft. above the floor, should be provided for water-closet compartments used by males. All partitions and doors should be of material and finish required in Sect. 67.

Note.—Wood is not recommended; if used, it should be hardwood.

Section 69. *Number of Closets and Urinals in Places of Industry.*—In every place of employment, whether heretofore or hereafter constructed, one water-closet should be provided for every 20 persons, or fraction thereof, of either sex.

In addition thereto, where more than 10 males are employed, one urinal should be provided for every 40 males, or fraction. Where not more than 10 males are employed, either a urinal should be provided or the water-closet should have a projecting lip and self-rising seat. Where trough urinals are used, each 2 ft. of trough should constitute one urinal.

Section 70. *Lavatories in Places of Industry.*—Adequate washing facilities should be provided in or near every toilet room. In new installations there should be at least one lavatory for every five fixtures (closets and urinals), or fraction.

Note.—One lavatory for every two or three fixtures is recommended.

Special washing facilities are required in certain industries, as (1) in industries where lead, arsenic, or other poisonous or injurious materials are handled by the employes; (2) in industries where food is prepared or manufactured, and (3) in glue factories, foundries, machine shops and other industries where the employes' hands become dirty or greasy. Except that in industries of the last mentioned class, located in small towns, where the employes go home at noon, this requirement may be waived by the proper authorities. In new installations there should be at least one lavatory for every ten employes, or fraction, and hot water should be provided. Basins or troughs, equipped with stoppers, for common use are usually prohibited.

Notes.—1. Washing facilities where the employe must necessarily wash in running water are recommended. A large trough without stopper, where each person washes in running water from an individual faucet, is generally better than separate bowls.

2. One lavatory or faucet for every five employes is recommended.

3. Adequate washing facilities are recommended for all industries.

4. Washrooms should be constructed according to the requirements for toilet rooms, as far as possible.

Section 71. *Schools.*—The following sanitary equipment conforms with requirements of most State and local units; in practice they are found adequate, chosen appliances and other operating conditions being favorable:

One water-closet for every 20 females or fraction, except for grammar and primary grades, where there should be one water-closet for every 15 females or fraction.

One water-closet and one urinal for every 40 males or fraction, except for grammar and primary grades, where there should be one water-closet and one urinal for every 30 males or fraction. Toilet accommodations for males and females should be placed in separate rooms with doors not less than 20 ft. apart. A drinking fountain and sink should be installed in each story and basement, for each 6000 sq. ft. of floor area, or fraction. A proper number of wash bowls should be provided.

Note.—Ordinarily there should be at least one wash bowl for every two closets and urinals. Wash bowls should be placed either in the toilet room or immediately outside. Drinking fountains should in no case be placed within the toilet room enclosure.

Section 72. *Theatres and Assembly Halls.*—Separate toilet rooms in connection with the auditorium should be provided for males and females. One closet should be installed for each 200 females or fraction, and one closet and one urinal for each 300 males or fraction, assuming the audience to be equally divided between males and females.

Section 73. *Apartment Houses, Hotels, Lodging Houses, Dormitories, Hospitals, Asylums, and Places of Detention.*—Every apartment should have a water-closet in a bathroom or separate compartment, except that where there are apartments consisting of but one or two rooms, there should be at least one water-closet for every two such apartments.

All other buildings of this classification should have at least one water-closet for every 15 rooms or fraction thereof.

Note.—Rooms with private water-closets should not be considered in counting either the number of rooms or the number of water-closets.

In every building of this classification where city water supply is available or can be made available, there should be at least one adequate sink or wash bowl with running water. In apartment houses there should be such a sink or wash bowl in each apartment.

Section 74. *When Water and Sewer Become Available.*—State and local regulations usually require that within a given time after water and sewer systems become available, water-closets, urinals, and lavatories shall be provided. When water and sewer are not available, other toilet and washing facilities must be provided (see chapter on "Waterless Toilet Conveniences").

Section 75. *Drinking Water.*—Every public building should be supplied with sufficient pure drinking water, and the faucets or outlets for the same should be placed conveniently for users. Common drinking cups are usually prohibited, for well-known hygienic reasons. Sanitary drinking fountains should be installed or individual cups provided (see Art. 19 in the preceding chapter.)

References

1. For detailed requirements regarding plumbing fixtures consult Sections 51 to 54 inclusive.
2. For piping and other regulations, consult preceding sections, also chapter on "Public Comfort Stations."
3. For requirements where public water supply and sewerage are not available, consult chapters on "Public Comfort Stations" and "Waterless Toilet Conveniences."

23. Suggestions for Engineers, Architects, and the General Public.—Where modern state laws or local ordinances on this subject exist, you will insure sanitary and reasonably durable plumbing if you provide in your specifications and contract with your plumber that all work must be performed in accordance with laws, rules and regulations, both state and local. You should require, further, that a certificate of inspection issued by the proper authority be furnished by the plumber before payment is made for the whole or any part of the system to be installed under the plans, specifications, agreement or contract.

When selecting plumbing fixtures for home, office, school, factory, or other types of buildings, make sure that they are of sanitary design and free from defects, and suitable for the purpose intended.

Experience has demonstrated that extra heavy cast-iron soil pipe with durable lead branches, bends, joints and connections properly supported and protected will render the most satisfactory service for ordinary residences or small buildings. For other buildings the plumbing and drainage should be designed to meet the construction of the building and the purpose for which it is to be used.

The use of cast-iron pipe for all underground house drains within the building is strongly recommended. It will cost slightly more to install but is safer from a sanitation standpoint and less liable to cause trouble by clogging due to settling or breakage.

The object of ventilation in a system of drainage or plumbing is to keep the air within the pipe in circulation and thus remove foul air caused by decomposition of solids; to prevent unequal air pressure within the system which may force trap seals or retard the flow of waste water; to prevent the pernicious effects of sewer gas on lead and iron pipes; and to protect the traps against siphonage. The avoidance of dead ends is essential.

Stoppage in sewers between the main in street and the building is due generally to one or more of the following causes, which in most cases is easily preventable: Insufficient fall, defective joints and connections, changes in direction improperly made, inadequate flushing, tree roots, grease and improper usage. Stoppages in the drainage system within the building are often caused by poorly made joints, improper connections, change of direction, insufficient flushing, grease, matches, hair pins, and other indifferent usage.

The cheapest method of installing plumbing and sewerage is not always the most economical in the end.

In spite of all the safeguards provided by states and cities, all plumbers do not show the same degree of efficiency in workmanship.

Plumbing that is properly installed and given reasonable care will not become insanitary nor dangerous to health.

Buildings intended for human habitation should be reasonably free from dampness, should have an abundant supply of pure fresh air, sunshine and pure water, and should be equipped with the essential sanitary conveniences.

Privy vaults, unclean plumbing fixtures (especially toilets and urinals), defective drains and the discharge terminals of drainage systems assist flies, rats and other vermin in spreading typhoid fever and other water-borne diseases.

When the use of disinfectants is required, consult your local health officer.

It is important that public toilet rooms be properly located, adequately designed, provided with plenty of light and air, and kept in good repair, clean and sanitary.

It is also important that tank pulls, seats, walls and floors be frequently and thoroughly cleaned and kept clean, and that they are made of such materials and construction that this can be done.

Materials of wood, and materials otherwise unprotected, should be kept well painted.

SECTION 6

ELECTRICAL EQUIPMENT

By C. M. Jansky

The use of electrically operated machinery and apparatus has become so extended that sooner or later some form of electrical equipment is installed in nearly every building. In order that the installation may be economical and efficient, provisions should be made in the first plans of the building for such installation and for the necessary wiring.

Although specific rules which will apply in every case without modification and adaptation cannot be given, nevertheless, there are many general principles which do apply and a knowledge of these will be of assistance in planning the installations.

1. Electrical Quantities.—The electrical terms that are commonly used in connection with electric installations are the names of electrical quantities such as energy, power, current, electromotive force or pressure, resistance, and the names of electrical apparatus. The electrical quantities have certain definite relations so that often if two are known, another, and sometimes more than one, may be calculated or determined by the aid of these relations.

2. Electrical Energy.—Although energy is not the simplest of electrical quantities, nevertheless as the purpose of most electrical installations is the efficient transformation and utilization of energy, it will be considered first. An electric motor or an electric lamp is merely a machine or device for transforming electrical energy. This energy is conveyed to the motor or to the lamp by means of wires. In order that the amount of energy used by different pieces of equipment may be compared or calculated, the energy must be measured. There are several units of energy in practical use, just as there are many units of volume or of length. The smallest practical unit of electrical energy is the *watt-second*. The watt-second is a very small unit so in practice a much larger one is used. The more common unit is the *kilowatt-hour*. A kilowatt-hour of energy is equal to 3,600,000 watt-seconds. A kilowatt-hour of energy, if converted into heat and utilized in melting ice, will melt 23.76 lb. It will light a 25-watt tungsten lamp for 40 hr., or operate a 1-horsepower motor for about 1⅓ hr. Energy is a physical quantity, and it is that which operates lamps and motors, heats flatirons, and for which payment is exacted by the public utility company.

3. Power.—Electrical apparatus is usually rated in terms of power—that is, in terms of the amount of energy the apparatus will consume or develop in some unit of time, usually the second or hour. Thus a motor that develops 1 kilowatt-hour in 1 hr. is said to be a 1-kilowatt motor. That is to say, power is the rate at which energy is being transferred, transformed or consumed. The unit of power is the *watt* or *kilowatt*. The *kilowatt* is 1000 times as large as the watt. The total amount of energy consumed by any piece of apparatus is obtained by multiplying the rate at which the energy is being consumed by the time of its operation. Thus a lamp rated as a 25-watt lamp is one that consumes 25 watt-seconds of energy in every second. In 1 hr. a 25-watt lamp will consume $25 \times 3600 = 90{,}000$ watt-seconds of energy, or $90{,}000 \div 1000 = 90$ kilo-watt-seconds. Since 1 kilowatt-hour = 3,600,000 watt-seconds, it will take a 25-watt lamp, $3{,}600{,}000 \div 90{,}000 = 40$ hr. to consume 1 kilowatt-hour of energy.

Illustrative Problem.—A 25-hp. motor is installed to operate an elevator. How many kilowatt-hours of energy will it consume in a 10-hr. day if the average load is only 15 hp. and the efficiency of the motor is 85%?

$$
\begin{aligned}
1 \text{ hp.} &= 746 \text{ watts.}\\
15 \text{ hp.} &= (15)(746) = 11{,}190 \text{ watts.}\\
(11{,}190)(10) &= 111{,}900 \text{ watt-hr.}\\
\frac{111{,}900}{1000} &= 111.9 \text{ kw.-hr. at } 100\% \text{ efficiency.}\\
\frac{111.9}{0.85} &= 131.6 \text{ kw.-hr. at } 85\% \text{ efficiency.}
\end{aligned}
$$

Illustrative Problem.—What will be the cost of operating twenty-five 60-watt lamps for a month, 6 hr. per day, at 8c. a kilowatt-hour?

$$(25)(60) = 1500 \text{ watts}$$
$$(1500)(6) = 9000 \text{ watt-hr. per day}$$
$$(9000)(30) = 270{,}000 \text{ watt-hr. per month.}$$
$$\frac{270{,}000}{1000} = 270 \text{ kw.-hr. per month.}$$
$$(270)(0.08) = \$21.60, \text{ cost per month}$$

4. Electrical Resistance.—Heat is one form of energy. The lighting of an incandescent lamp is due to the heating effect of electrical energy in the filament of the lamp. In other words, the lighting is produced by the conversion of electrical energy into heat by a property of the filament. This property is called *resistance.* The unit of resistance is the *ohm.* In concrete relations, the ohm is defined as the resistance of a column of mercury 106.3 centimeters long of uniform cross section and one square millimeter in cross section, at a temperature of melting ice. A length of 1000 ft. of No. 10 copper wire at a temperature of 25 deg. C. or 77 deg. F., has a resistance of one ohm. This is a concrete relation more easily remembered. In terms of energy units, it may be defined as that resistance in which one ampere will develop one joule of energy per second.

5. Effect of Temperature Upon Resistance.—When a metallic conductor is heated either externally or by the passage of an electric current, its resistance is increased. The resistance of electrolytes and of carbon decreases as their temperature increases or rises. This relation is expressed by the formula

$$R_t = R_o(1 + a_c t_c)$$

where t_c is expressed in degrees centigrade, and

$$R_t = R_o(1 + a_f t_f)$$

where the temperature change is expressed in Fahrenheit degrees. a is called the temperature coefficient. For pure metals $a_c = 0.00392$ and $a_f = 0.0022$. For electrolytes a is negative.

6. Electric Current.—Energy may be transferred from the point of its development to the point of its utilization in many ways. The common mechanical means are the spur gear, the belt, the cable, a stream or current of water, current of steam, and current of electricity.

In the first five cases the material body is a vehicle for transferring the energy, and its motion transfers the energy. In an electric circuit, the matter or material body connecting the source of energy with the instrument or apparatus where it is utilized does not move, but the energy is transferred by a current or stream of electricity. Perhaps in light of modern theory we should say of a current of electrons. Like water or steam the electricity (or electrons) is a vehicle of energy, and energy is said to be transferred by a current of electricity.

The practical unit current is the *ampère.* An ampere may be defined in many ways but for our purpose it may be defined as that current which will develop one watt-second, or one joule per second, of heat in a conductor whose resistance is 1 ohm. Another and more practical definition is basd on the chemical action of an electric current. Based on this principle an ampere is such a current as will deposit 1.118 milligrams of silver in 1 second from a standard solution of silver nitrate.

7. Electromotive Force or Electrical Pressure.—In order that a current of water or steam may transfer energy from one point to another, there must be a difference of pressure between the points. If there is no difference of pressure, no current will flow and no energy will be transferred.

In an analogous way the transfer of electrical energy from its source to points of utilization is due to difference of electrical pressure or electromotive force. Electromotive force is thus the cause of the flow of electricity which constitutes the current. The practical unit of electrical pressure is the *volt.* The volt may also be defined in many ways, but in terms of the units already defined, we may say that a volt is the pressure that will send a current of 1 ampere through a resistance of 1 ohm.

8. Ohm's Law.—The three physical quantities, electrical pressure, current, and resistance are related in a definite way, known as Ohm's law. This law is deduced from the results of experiments. It states that the current in a circuit is strictly proportional to the total electromotive force in the circuit. If we represent the current in amperes by I, the pressure in volts by E and the resistance in ohms by R, then in direct current circuits, Ohm's law is written

$$I = \frac{E}{R} \qquad R = \frac{E}{I} \qquad IR = E$$

Illustrative Problem.—A flatiron takes 4 amperes when connected to a 110-volt circuit. What is the resistance of the iron?

By Ohm's law, $R = \frac{E}{I}$ $E = 110$ volts $I = 4$ amperes

$\therefore R = \frac{110}{4} = 27.5$ ohms

Illustrative Problem.—What pressure is required to send one-half ampere through a 220-ohm lamp?

By Ohm's law, $E = IR$. $I = \frac{1}{2}$ ampere. $R = 220$ ohms.
$\therefore E = (\frac{1}{2})(220) = 110$ volts.

Illustrative Problem.—A direct current pressure of 110 volts is connected to an electric chafing dish whose resistance is 22 ohms. What current does the chafing dish take?

By Ohm's law, $I = \frac{E}{R}$ $= 110$ volts $R = 22$ ohms

$\therefore I = \frac{110}{22} = 5$ amperes

9. Pressure or Voltage Drop.—In order that a current may flow through a conductor there must be a difference of electrical pressure between any two points on the conductor. If E_1 is the electrical pressure at one point and E_2 a lower pressure at another point, then $E_1 - E_2$ is the pressure drop. If R is the resistance of the conductor between two points, then by Ohm's law

$$\frac{E_1 - E_2}{R} = I$$

and

$$E = E_1 - E_2 = IR$$

In other words, the voltage drop between any two points of a conductor is equal to the product of the current flowing by the resistance of the conductor between the two points. The voltage drop across an incandescent lamp is the voltage between its two terminals and is equal to the current multiplied by the resistance of the lamp.

Illustrative Problem.—The current taken by a motor is 50 amperes. The motor is connected to a generator by wires whose resistance is 0.08 ohm. If the generator voltage is 220 volts, what is the pressure at the motor?

The voltage drop is IR. $I = 50$ amperes, $R = 0.08$ ohms. Then voltage drop $= (50)(0.08) = 4$ volts. The pressure at the motor is the difference between the generator voltage and the voltage drop or $220 - 4 = 216$ volts.

10. Heat Developed in a Wire.—The amount of heat developed by a current in a resistance was experimentally determined to be directly proportionate to the product of the resistance by the square of the current flowing by the time. Expressed algebraically this relation is given by

$$\text{Heat} = kI^2Rt$$

When I is expressed in amperes, R in ohms, and t in seconds, k is unity and the heat developed is expressed in watt-seconds. To express the heat in calories, k becomes 0.24 and the formula is

$$\text{Heat} = 0.24I^2Rt \text{ calories}$$

There are many examples of the heating effect of an electric current. The most common is the incandescent lamp in which a small filament of wire is heated to incandescence by the current. Likewise, electric flatirons, toasters and electric furnaces exemplify the same principle. Some heat is developed in every wire through which an electric current flows. In some cases, such as mentioned above, this heat is utilized, but in connecting wires and all light and power wires, this heat is wasted. In order to keep the loss within reasonable bounds the wires must have low resistance, especially where they carry heavy currents any distance as it is evident

from the formula that the heat developed is proportional to the square of the current. Doubling the current quadruples the heat generated in the same resistance.

The currents that copper wires will carry without over-heating, have been determined by the engineers of the National Board of Fire Underwriters. A table giving these currents is found on p. 1296.

When the current is measured in amperes and the resistance in ohms, k is 1, and we have joules $= I^2R$ per second, or watts $= I^2R$. But by Ohm's law, $IR = E$, and $I^2R = IE$. Therefore, $IE =$ watts. That is, if the difference of pressure between two points of a conductor is E volts when a current of I amperes is flowing, there are IE watts of power being spent in the conductor between the two points. In t seconds, the energy spent will be EIt watt-seconds, or joules.

Illustrative Problem.—How many watt-seconds or joules of heat are developed in an hour in an electric stove which takes a current of 10 amperes and whose resistor has a resistance of 11 ohms?

Heat (joules) $= I^2Rt$, $I = 10$ amperes, $R = 11$ ohms, $t = 1$ hr. $= 3600$ sec

$$\therefore \text{Heat} = (10^2)(11)(3600) = 3{,}960{,}000 \text{ joules} = 1.1 \text{ kw.-hr.}$$

Illustrative Problem.—What is the voltage drop across the resistor of preceding problem?

The voltage drop $= IR = (10)(11) = 110$ volts. But watts = volts × amperes, then 110 volts × 10 amperes = 1100 watts. 1100 watts supplied for one hour equals 1.1 kw.-hr. as above.

Illustrative Problem.—A tungsten lamp takes ¼ ampere at 110 volts. How much power is necessary to light the lamp?

Power $= EI$. $E = 110$ volts, $I = \frac{1}{4}$ ampere.

$$\therefore \text{Power} = (110)(\tfrac{1}{4}) = 27.5 \text{ watts.}$$

Illustrative Problem.—A 110-volt coffee percolator consumes 440 watts. What current does it take?

Power or watts $= IE$. Then, $I = \frac{\text{watts}}{E}$. Watts $= 440$, and $E = 110$ volts

$$\therefore I = \frac{440}{110} = 4 \text{ amperes.}$$

Illustrative Problem.—A current of 5 amperes flows through a 475-watt flatiron. What is the resistance of the flatiron?

$I^2R =$ watts. Then $R = \frac{\text{watts}}{I^2}$. Watts $= 475$, and $I^2 = (5)(5) = 25$.

$$\therefore R = \frac{475}{25} = 19 \text{ ohms.}$$

Illustrative Problem.—How many watts are wasted in a 2-ohm rheostat when 25 amperes are flowing?

Watts $= I^2R$. $I^2 = (25)(25) = 625$, $R = 2$ ohms.

$$\therefore \text{Watts} = (625)(2) = 1250 = 1.25 \text{ kw.}$$

The energy spent in any given time is equal to the product of the power by the time. Since $I \times E =$ power, then $I \times E \times t =$ energy. If t is in seconds, the product $IEt =$ joules or watt-seconds. If t is in hours, then IEt is watt-hours, and since 1000 watts = 1 kw., then $\frac{IEt}{1000} =$ kilowatt-hours.

Illustrative Problem.—How many kilowatt hours of energy is consumed by an electric range in 3 hr. if it requires 3500 watts for its operation?

$$\frac{\text{watts} \times \text{hours}}{1000} = \text{kilowatt-hours}$$

$$\therefore \frac{(3500)(3)}{1000} = 10.5 \text{ kw.-hr.}$$

Illustrative Problem.—Ten 25-watt tungsten lamps are burned on an average of 4 hr. per day for a month of 30 days. What is the monthly consumption?

$\frac{\text{watts} \times \text{hours}}{1000} =$ kilowatt-hours. Watts $= (10)(25) = 250$ Hours $= (30)(4) = 120$

$$\therefore \frac{(120)(250)}{1000} = 30 \text{ kw.-hr.}$$

Illustrative Problem.—A 10-hp motor is operated on an average of 8 hr. per day at full load. What will be the monthly bill assuming operation for 26 days at 5c. a kilowatt-hour?

$\frac{\text{watts} \times \text{hours}}{1000} =$ kilowatt-hours. 1 hp. = 746 watts; then watts $= (10)(746) = 7460$. Hours $= (26)(8) = 208$.

$$\therefore \frac{(7460)(208)}{1000} = 1551.68 \text{ kw.-hr., and } (1551.68)(0.05) = \$77.58.$$

11. Electric Circuit.—When steam is used to transfer energy or to do work, it is conveyed from one point to another point by means of pipes. In the most efficient systems the steam is not permitted to escape after it has parted with its energy, but by means of return pipes, condenser, etc., it is returned to the boiler whence it started. It is thus made to pass through or around a path or circuit. It is kept in this path by pipes.

In an analogous way, electricity is conducted from one place to another by metallic conductors, and the metallic wires, along which the electric current flows from the generator to the lamp or other apparatus, are called the electric circuit. When every part of the circuit is metallic the current can flow and the circuit is said to be closed. An open circuit is a discontinuous circuit, or one in which there is a break.

All substances will not carry electricity with the same facility, hence substances are classified as *conductors* and *insulators*.

Conductors are substances which permit the electric current to flow with comparative ease. Most metals are good conductors, copper being one of the best.

Insulators are substances which do not transmit electricity with ease. Glass, porcelain, rubber, paraffin, shellac (dry), etc., are insulators. Both conductors and insulators are needed in an electric circuit; the conductor to form the path of the current and the insulator to prevent its escape. The wires commonly used in forming electrical circuits are therefore insulated.

12. Kinds of Electric Currents.—There are two kinds of electric currents in use, direct and alternating. Although there is no essential difference in the electricity, the manner in which it is made to flow develops distinguishing properties. A direct current is one in which the electricity, or electrons if we wish to use modern terms, is continually flowing in the same direction. The amount that flows per second may vary, but the direction of flow does not. A direct current is thus a continuous current so long as the circuit is closed. A battery is the best example of the source of a direct current. The current flows out at one electrode and returns to the other.

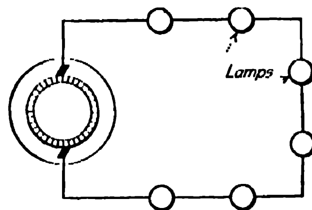


Fig. 1.

An alternating current is one whose intensity is constantly changing and whose direction of flow is reversed periodically. The motion of a pendulum is a good analogy for an alternating current. The speed of the pendulum constantly changes from one extreme position of its swing to the other extreme, and at these points it changes its direction of motion. In the same way, when a source of alternating electromotive force, such as an alternating-current generator, is connected to a circuit, the current rises from zero to a maximum value, decreases from this value to zero when it reverses its direction of flow and then increases to a maximum value in the opposite direction, and again decreases to zero. This cycle is repeated many times a second so long as the current flows. The number of cycles per second is called the frequency. The common frequencies in this country are 60 cycles per second for power and light, and 25 cycles per second for power. Twenty-five cycle current is sometimes also used for lighting but it is not so satisfactory on account of the resulting flickering of light.

13. Kinds of Circuits.—Energy is conveyed from its source to points of utilization by wires or conductors forming circuits. Circuits are classified with reference to the manner in which the energy is distributed by the electrical current, and also with reference to the kind of current; that is, direct or alternating.

The first method of classification gives *series circuits* and *divided circuits*. Divided circuits may be merely parallel circuits, or a combination of parallel and series circuits. A good example of series circuit, is the ordinary series street lighting circuit (Fig. 1). In the series circuit, the current passes undiminished through each part of the circuit. Different parts of the circuit may, however, absorb equal or different amounts of energy.

In the parallel circuit (Fig. 2), the current does not maintain a constant value throughout different parts of the circuit but is subdivided, each utilizing or energy-consuming device diverting some of the current. These parallel circuits may be equal or unequal depending upon

the design of the apparatus. The main advantage of the parallel circuit over the series circuit is the fact that it permits the subdivision of the electric current so that small and large energy-utilizing devices may be supplied from the same source. Indoor incandescent lighting circuits are invariably parallel circuits.

The circuits shown in Figs. 1 and 2 are what are known as two-wire circuits. Energy-utilizing devices such as lamps or motors in a series circuit, must be designed for the same current although the voltage drop across their terminals may be different. Apparatus intended for parallel connection must be designed for the same voltage but may have very much different current-carrying capacity. Thus, a 10-watt 110-volt lamp, a 450-watt 110-volt lamp and a 10-hp. motor may all be operated from the same pair of mains. The first lamp will take a current of less than 0.1 ampere while the motor will take a current of over 67 amperes at full load.

It has been shown that the energy lost in wires is proportional to the square of the current, hence if much energy is to be utilized at a considerable distance from its source, it is preferable to raise the voltage and reduce the current, but incandescent lamps designed for higher than 110 volts cannot be made readily for low-energy consumption. To utilize the higher voltage and also to use small low-voltage lamps, there has been designed the three-wire circuit shown in Fig. 3. The three-wire circuit is common especially in large cities.

14. Electrical Machines and Apparatus.—Electrical machines and apparatus are of three kinds: That by means of which the energy is developed or generated; that in which, or by which, the energy is utilized; and that used for transforming the energy either from one voltage to another or from alternating current to direct current, or vice versa.

The machines used for developing energy are called generators. Generators are classified as direct current and alternating current. The utilizing machines and apparatus are of various

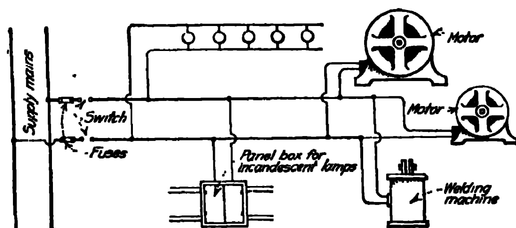


FIG. 2.

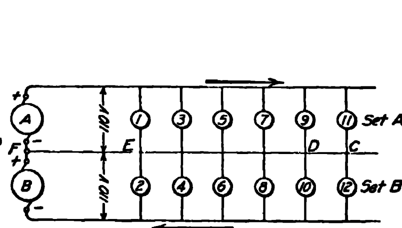


FIG. 3.

forms. Those used for power purposes are called motors. Most of the other forms depend on their operation upon the heating effect of the electric current. The incandescent lamp, electric flatiron, and electric stove are good examples.

The transforming apparatus is of four forms—static transformers, rotary or synchronous converters, motor generators, and rectifiers.

The static transformer is used to change alternating current at one voltage to alternating current at another voltage. The house voltage is usually 110 volts while the voltage between line wires may be 2300 volts or higher. By means of the transformer, the line voltage is stepped down so that it may be safely used in buildings.

A synchronous converter is a combination of an alternating-current motor and a direct-current generator in one machine. Alternating current entering at one end of the armature drives the machine, while direct current is taken from the armature at the other end.

A motor-generator is merely a combination of two separate machines, an a.-c. motor and a d.-c. generator, or a d.-c. motor and an a.-c. generator, depending upon which machine is the driver and which is the driven.

Rectifiers are devices for changing alternating current to direct current. The most important of these are for power purposes. For battery charging and for radio service there are several forms of electrolytic rectifiers on the market.

Generators are installed in isolated plants and in central stations. Where central station power is available, as in cities, generators are seldom installed anywhere except at the central station, but motors are installed in many buildings where power machinery is used. Motors are rated in horsepower or kilowatts, the rating being the full load output. Since motors never have an efficiency of 100%, the current intake of the motors will always be higher than that indicated by the rating. To convert the horsepower rating into watts, multiply by 746.

Illustrative Problem.—What is the current intake of a 25-hp. 220-volt d.-c. motor whose efficiency is 85%?

1 hp. = 746 watts. 25 hp. = (25)(746) = 18,650 watts.

$$\text{Watts intake} = \frac{18{,}650}{0.85} = 21{,}940 \text{ watts.} \quad \text{Current} = \frac{\text{watts}}{\text{volts}} = \frac{21{,}940}{220} = 99.7 \text{ or } 100 \text{ amperes}$$

The following table gives the full load currents taken by d.-c. motors of the more common sizes and voltages, together with other useful data.

Wiring Table for Direct-current Motors

Horse-power	Voltage[1]	Approx. full-load current	Size of fuses	Size of switch	Size of wire, B. & S. gage	Horse-power	Voltage[1]	Approx full-load current	Size of fuses	Size of switch	Size of wire, B. & S. gage
	110	2.4	6	10	14		110	232.0	300	300	300,000
1/4	220	1.2	3	5	14	30	220	116.0	150	150	00
	500	0.5	1	5	14		500	50.8	70	75	3
	110	4.8	6	10	14		110	270.0	350	400	450,000
1/2	220	2.4	4	5	14	35	220	135.0	175	200	000
	500	1.0	2	5	14		500	59.2	75	75	3
	110	8.4	12	15	14		110	310.0	400	400	500,000
1	220	4.3	6	10	14	40	220	155.0	200	200	200,000
	500	1.8	3	5	14		500	67.8	90	100	2
	110	17.0	25	25	10		110	377.0	500	500	700,000
2	220	8.5	12	15	14	50	220	188.5	250	250	250,000
	500	3.7	5	5	14		500	83.0	110	100	1
	110	20.0	25	25	10		110	452.0	550	600	900,000
2 1/2	220	10.0	15	15	12	60	220	226.0	300	300	350,000
	500	4.4	6	10	14		500	99.5	125	150	0
	110	24.0	30	30	8		110	528.0	660	600	1,000,000
3	220	12.0	15	25	12	70	220	264.0	325	300	400,000
	500	5.3	8	10	14		500	116.0	150	150	00
	110	28.0	35	35	8		110	568.0	710	800	1,200,000
3 1/2	220	14.0	20	25	12	75	220	284.0	350	400	450,000
	500	6.0	8	10	14		500	124.0	150	150	00
	110	40.0	50	50	6		110	604.0	755	800	1,300,000
5	220	20.0	25	25	10	80	220	302.0	375	400	500,000
	500	8.8	12	15	14		500	133.0	175	200	000
	110	60.0	75	75	3		110	680.0	850	800	1,500,000
7 1/2	220	30.0	40	50	8	90	220	340.0	450	400	600,000
	500	13.5	18	15	12		500	149.0	200	200	200,000
	110	80.0	100	100	1		110	746.0	933	1000	1,700,000
10	220	40.0	50	50	5	100	220	373.0	450	400	600,000
	500	17.5	25	25	10		500	164.0	200	200	200,000
	110	120.0	150	150	00		110	934.0	1168	1200	2,105,500
15	220	60.0	75	75	3	125	220	467.0	600	600	900,000
	500	26.3	35	30	8		500	205.0	250	300	250,000
	110	154.0	200	200	0000		110	1106.0	1383	1200	2,400,000
20	220	77.0	100	100	0	150	220	553.0	691	600	1,100,000
	500	34.0	45	50	6		500	245.0	300	300	350,000
	110	192.5	250	250	250,000						
25	220	96.3	125	150	0						
	500	42.4	60	75	5						

[1] 110-volt data applies to voltages of from 100 to 125 volts, 220-volt data to 200 to 250 volts and 500-volt data to 500 to 600 volts.

15. Alternating-current Generators.—Alternating-current generators are classed as single-phase, two-phase or quarter-phase, and three-phase. The first and last mentioned are the most common. The single-phase generator has a continuous winding on the armature in which there is developed a single current which fluctuates as described in Art. 12. The single-phase generator supplies current to either a two-wire or a three-wire circuit.

A two-phase generator has two sets of coils on the armature. These coils are located so that when the current in one set is a maximum, that in the other set is zero, and vice versa. They are the equivalent of two single-phase generators whose currents differ in phase by one-quarter of a period. Two-phase generators supply current to four-wire circuits. Sometimes two-phase currents are distributed by three-wire circuits.

A three-phase generator has three sets of coils on the armature. The coils may be connected so as to form a closed circuit (delta connection), or the three sets may have one end of each set connected to a common point (Y connection). The currents in these sets of coils differ in phase by one-third of a period. Three-phase generators are commonly used for generating currents for power purposes and supply current to three-, four- or six-wire circuits.

Alternating-current generators are rated in kilovolt-amperes, kv-a. The output in watts is equal to the kilovolt-amperes multiplied by the power factor of the load circuit. The power factor is determined by the characteristic of the load and may have any value from 0 to 1. The power factor of direct-current circuits is 1. The alternating current taken by any receiving circuit or energy-consuming device can not be calculated from the pressure and current alone, but the power factor must also be known. If we represent the current output of an alternator by I, the e.m.f. between line wires by E, and the power factor by K, then the power output of the three types of generators is given by

$$\text{Single-phase power} = KEI$$
$$\text{Two-phase power} = 2KEI$$
$$\text{Three-phase power} = 1.732KEI.$$

Illustrative Problem.—A single-phase generator supplies 150 amperes to a circuit at 550 volts. What power is supplied to the circuit if its power factor is 0.75?

Power = KEI watts. $K = 0.75$, $E = 550$, and $I = 150$.

∴Power = (0.75)(150)(550) = 61,875 watts = 61.875 kw.

Illustrative Problem.—The line voltage of a three-phase generator is 2300 volts; the line current is 50 amperes How much power is it supplying if the power factor of the load is 0.80?

Power = $1.732KEI$. $K = 0.80$, $E = 2300$, and $I = 50$ amperes.

∴Power = (1.732)(0.80)(2300)(50) = 159,344 watts = 159 344 kw.

16. Alternating-current Motors.—There are several types of a-c. motors in common use, the distinction between them being due to their construction and manner of operation. The more common types are:

(*a*) *Single-phase Series Commutator Motors.*—These are practically the same as d.-c. series motors in general features of construction and are supplied by two-wire circuits.

(*b*) *Synchronous Motors.*—These are practically the same as a.-c. generators, but instead of developing alternating current, they are driven by it. They are essentially constant speed machines.

(*c*) *Induction Motors.*—These are the most common type of a.-c. motors. The essential features of this type of motor are a stationary winding and a short-circuited rotary winding. When an alternating current is passed through the stationary winding a revolving magnetic field is produced. This revolving magnetic field develops a current in the rotating element and a drag results, causing the rotary element to turn. Induction motors are made for single-phase and polyphase currents.

The current intake of an induction motor varies considerably with the load. The smaller, up to 25 hp., induction motors are commonly started by connecting them directly across the line. The starting current is thus from one to 3.5 times the full-load current depending upon the size of the motor. Provision must be made for this when wiring for such motors.

Table on p. 1374 gives the currents for induction motors of different sizes.

Switches should have a rated capacity at least as large as the rated capacity of the fuse protecting the circuit,

or, if the circuit is protected by a circuit breaker, the switch should have such capacity that the breaker will be set to be opened by a current not greater than 30% in excess of the current rating of the switch.

17. Household Appliances.—Owing to their convenience, the use of household appliances is rapidly extending. The following table gives the powers consumed, the current intake, the size of connecting wires and other useful data for many domestic and commercial appliances:

Appliances	Watts consumed	Amperes at 110 volts	Size of wire (rubber covered)	Fuse (amperes)
Broilers, 3 ht.	300 to 1200	3 to 11	14	6 to 15
Chafing dishes, 3 ht.	200 to 500	1.8 to 4.6	14	6
Cigar lighters	75	0.7	14	3
Coffee percolators for 6 in. stove	100 to 440	1 to 4	14	3 to 6
Corn poppers	300	2.7	14	6
Curling iron heaters	60	0.6	14	3
Double boilers for 6 in. 3 ht. stove	100 to 440	1 to 4	14	3 to 6
Flatiron—3 lb	275	2.5	14	6
Flatiron—4 lb	350	3.2	14	6
Flatiron—5 lb	400	3.6	14	6
Flatiron—6 lb	475	4.3	14	6
Flatiron—7.5 lb	540	4.9	14	10
Flatiron—9 lb	610	5.6	14	10
Frying kettles, 8 in. diam	825	7.5	14	10
Griddle cake cookers, 9 × 12 in., 3 ht	330 to 880	3 to 8	14	10
Griddle cake cookers, 12 × 18 in., 3 ht	500 to 1500	4.6 to 13.7	14	6 to 15
Heating pads	50	0.5	14	3
Instantaneous flow water heaters	2000	18.2	12	25
Nursery milk warmers	450	4.1	14	6
Ovens	1200 to 1500	11 to 13.7	14	15
Plate warmers	300	2.7	14	6
Radiators	700 to 6000	6.4 to 56	14 to 4	10 to 75
Ranges: Three heats, 4 to 6 people	1000 to 4515	9.1 to 41	14 to 6	10 to 50
Ranges: Three heats, 6 to 12 people	1100 to 5250	10 to 47.5	14 to 6	10 to 50
Ranges: Three heats, 12 to 20 people	2000 to 7200	18.2 to 65.5	12 to 4	20 to 70
Shaving mugs	150	1.4	14	3
Stoves (plain) 4.5 in., 3 ht.	50 to 220	0.46 to 2	14	3
Stoves (plain) 6 in., 3 ht.	100 to 440	1 to 4	14	6
Stoves (plain) 7 in., 3 ht.	120 to 600	1.1 to 5.5	14	6
Stoves (plain) 8 in., 3 ht	165 to 825	1.5 to 7.5	14	3 to 10
Stoves (plain) 10 in., 3 ht.	275 to 1100	2.5 to 10	14	3 to 10
Stoves (plain) 12 in. 3 ht.	325 to 1300	2.95 to 12	14	6 to 15
Stove, traveler's	200	1.82	14	3
Toasters, 9 × 12 in., 3 ht.	330 to 880	3 to 8	14	6 to 10
Toasters, 12 × 18 in., 3 ht.	500 to 1500	4.6 to 14	14	6 to 15
Urns, 1-gal., 3 ht.	110 to 440	1 to 4	14	6
Urns, 2-gal., 3 ht.	220 to 660	2 to 6	14	6
Urns, 3-gal., 3 ht.	330 to 1320	3 to 12	14	6 to 15
Urns, 5-gal., 3 ht.	400 to 1700	3.7 to 15.5	14 to 12	6 to 20
Waffle irons, 2 waffles	770	7	14	10
Waffle irons, 3 waffles	1150	11	14	15

18. Interior Wiring.—Electrical energy for lighting and power is conveyed into, and distributed throughout, buildings by means of insulated wires.

In general, wiring systems may be classified in accordance with the kind of current they carry; that is, direct or alternating. For low-voltage interior circuits there is little difference in the two systems. Another classification is based on the number of wires used in a circuit. According to this classification we have two-wire and three-wire systems. The two-wire system may be either a series or parallel system. It consists essentially of two wires by which the current passes to and from the lamps or other energy-consuming devices. Fig. 4 is a diagram of a two-wire parallel wiring system. Two-wire circuits may be supplied by direct cur-

rent or by alternating current. The alternating current may be supplied by a single-phase generator when the circuits are as shown in Fig. 4, or the source may be a two-phase or three-phase generator. When polyphase generators are used for supplying energy to two-wire circuits,

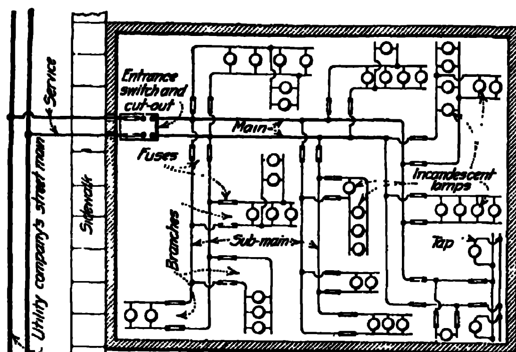


Fig. 4.

the connections are made as shown in Fig. 5. For satisfactory operation the load in each phase should be approximately the same.

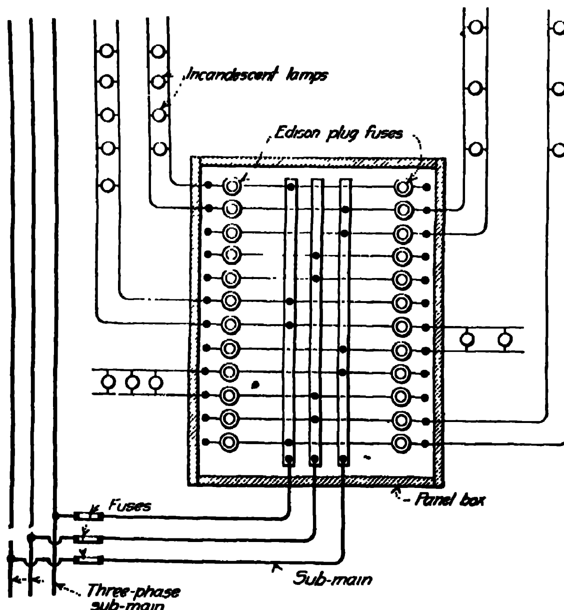


Fig. 5.

19. Three-wire Systems.—As already explained, three-wire systems are designed to permit the use of higher voltages with low-voltage lamps. The source of energy for a three-wire system may be either a three-wire, d.-c. generator or a two-wire d.-c. generator with a proper balancer set. Fig. 3 shows the connections for a three-wire circuit supplied by two two-wire

generators giving double the voltage ot the lamps. When the loads between the outside wires and the middle or mutual wire are equal, the system is said to be balanced. When this condi-

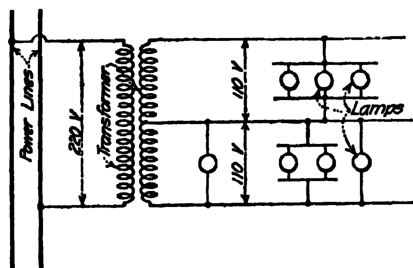


Fig. 6.

tion is fulfilled, the middle wire carries no current; when this condition is not fulfilled the neutral wire carries the excess of current in one outside wire above that in the other outside wire.

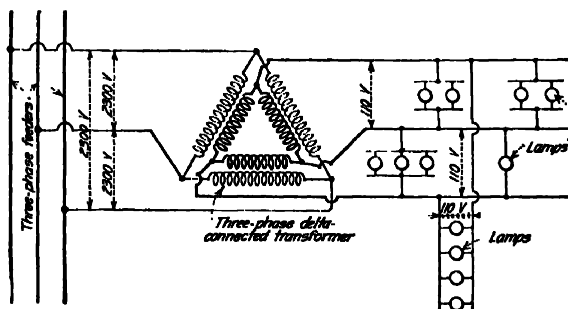


Fig. 7.

Three-wire circuits are also supplied by single-phase and polyphase alternating-current generators through transformers. A single-phase three-wire circuit is shown in Fig. 6.

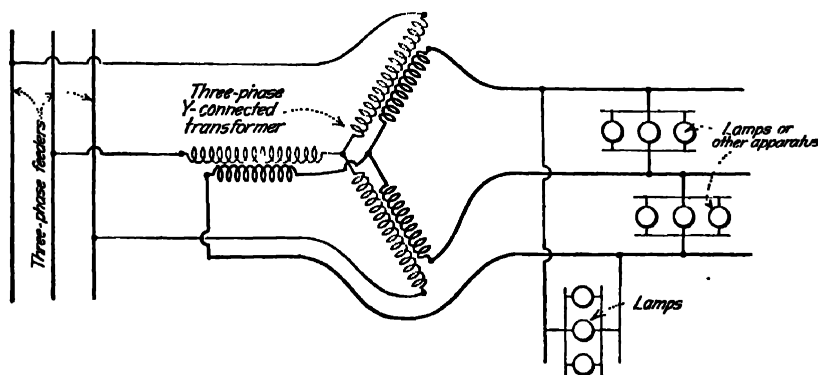


Fig. 8.

The secondary winding of transformers consists of two coils which may be connected in series or parallel, hence they are well adapted for supplying three-wire circuits. The three-phase three-wire circuit differs somewhat

from the three-wire circuit described above. in that it essentially consists of three two-wire circuits that are interconnected. The energy is supplied and distributed by three wires but the circuits are so connected that any wire may be considered as the return wire for either of the other two. Such a system is shown in Figs. 7 and 8.

20. Calculation of D-C. Circuits.—Most electrical energy-utilizing devices are built so as to operate satisfactorily at a constant voltage. This necessitates that the wires along which the energy is supplied be of proper size. There are two conditions that determine the proper size of wire; one is the voltage drop, and the other is heating. The safe current carrying capacity of wires is given in following table.

TABLE OF ALLOWABLE CARRYING CAPACITIES OF WIRE

B. & S. gage number	Diameter of solid wire in mils (1 mil = 0.001 in.)	Area in circular mils	Rubber insulation (amperes)	Other insulation (amperes)
18	40.3	1,624	3	5
16	50.8	2,583	6	10
14	64.1	4,107	15	20
12	80.8	6,530	20	25
10	101.9	10,380	25	30
8	128.5	16,510	35	50
6	162.0	26,250	50	70
5	181.9	33,100	55	80
4	204.3	41,740	70	90
3	229.4	52,630	80	100
2	257.6	66,370	90	125
1	289.3	83,690	100	150
0	325.0	105,500	125	200
00	364.8	133,100	150	225
000	409.6	167,800	175	275
		200,000	200	300
0000	460.0	211,600	225	325
		300,000	275	400
		400,000	325	500
		500,000	400	600
		600,000	450	680
		700,000	500	760
		800,000	550	840
		900,000	600	920
		1,000,000	650	1,000
		1,100,000	690	1,080
		1,200,000	730	1,150
		1,300,000	770	1,220
		1,400,000	810	1,290
		1,500,000	850	1,360
		1,600,000	890	1,430
		1,700,000	930	1,490
		1,800,000	970	1,550
		1,900,000	1,010	1,610
		2,000,000	1,050	1,670

Table of Allowable Carrying Capacities of Stranded Conductors

Strands			Cable		Allowable carrying capacities, amperes		
Number of strands	Mils diameter	B. & S. gage number	Area in circular mils	Outside diameter over copper	Table *A* rubber insulation	Table *B* varnished cloth insulation	Table *C* other insulation
7	25	22	4,490	0.075	15	18	20
7	32	20	7,150	0.096	20	25	25
7	40	18	11,370	0.120	25	30	35
7	51	16	18,080	0.153	35	40	50
7	64	14	28,740	0.192	50	60	70
7	81	12	45,710	0.253	70	85	90
7	91	11	58,000	0.273	80	95	110
7	102	10	72,680	0.306	90	110	130
19	64	14	78,030	0.320	100	120	150
19	72	13	98,380	0.360	125	150	175
19	81	12	124,900	0.405	150	180	210
19	91	11	157,300	0.455	175	210	250
19	107	*	217,500	0.540	225	270	325
19	114	9	248,700	0.570	250	300	350
37	91	11	306,400	0.637	275	330	400
37	97	*	317,500	0.679	300	360	450
37	102	10	381,200	0.714	325	390	500
37	116	*	481,300	0.798	400	480	600
61	102	10	633,300	0.918	475	565	700
61	107	*	698,000	0.963	500	600	750
61	114	9	798,300	1.030	550	660	825
61	121	*	893,100	1.090	600	720	900
61	128	8	1,007,000	1.150	650	780	1,000
91	114	9	1,191,000	1.250	725	870	1,125
91	128	8	1,502,000	1.410	850	1,020	1,350
127	114	9	1,660,000	1.480	900	1,100	1,460
127	128	8	2,097,000	1.660	1,100	1,300	1,700

21. Wire Measurements.—The units for measuring wire are the foot, mil, and circular mil. The mil is 1/1000 in. and is used in measuring diameter of electrical conductors. The circular mil is the area of a circle 1 mil in diameter. Since areas of circles are to each other as the squares of their diameters, the area of any circular cross section in circular mils is equal to the square of the diameter in mils. Thus, a wire of 1/10-in. diameter has a cross-sectional area of $100 \times 100 = 10{,}000$ cir. mils. To facilitate the determination of the proper size of wire, tables have been prepared giving the gage numbers, diameter, cross-sectional area, resistance per 1000 ft. at different temperatures, and other data depending upon the completeness of the tables. A practical table is the following:

Working Table—Standard Annealed Copper Wire

English Units, American Wire Gage (B. & S.)

Gage No	Diameter in mils	Cross section		Ohms per 1000 feet		Pounds per 1000 feet
		Circular mils	Square inches	25° C. (= 77° F.)	65° C. (= 149° F.)	
0000	460.0	212,000.0	0.166	0.0500	0.0577	641.0
000	410.0	168,000.0	0.132	0.0630	0.0728	508.0
00	365.0	133,000.0	0.105	0.0795	0.0918	403.0
0	325.0	106,000.0	0.0829	0.100	0.116	319.0
1	289.0	83,700.0	0.0657	0.126	0.146	253.0
2	258.0	66,400.0	0.0521	0.159	0.184	201.0
3	229.0	52,600.0	0.0413	0.201	0.232	159.0
4	204.0	41,700.0	0.0328	0.253	0.293	126.0
5	182.0	33,100.0	0.0260	0.320	0.369	100.0
6	162.0	26,300.0	0.0206	0.403	0.465	79.5
7	144.0	20,800.0	0.0164	0.508	0.587	63.0
8	128.0	16,500.0	0.0130	0.641	0.740	50.0
9	114.0	13,100.0	0.0103	0.808	0.933	39.6
10	102.0	10,400.0	0.00815	1.02	1.18	31.4
11	91.0	8,230.0	0.00647	1.28	1.48	24.9
12	81.0	6,530.0	0.00513	1.62	1.87	19.8
13	72.0	5,180.0	0.00407	2.04	2.36	15.7
14	64.0	4,110.0	0.00323	2.58	2.97	12.4
15	57.0	3,260.0	0.00256	3.25	3.75	9.86
16	51.0	2,580.0	0.00203	4.09	4.73	7.82
17	45.0	2,050.0	0.00161	5.16	5.96	6.20
18	40.0	1,620.0	0.00128	6.51	7.52	4.92
19	36.0	1,290.0	0.00101	8.21	9.48	3.90
20	32.0	1,020.0	0.000802	10.4	12.0	3.09
21	28.5	810.0	0.000636	13.1	15.1	2.45
22	25.3	642.0	0.000505	16.5	19.0	1.94
23	22.6	509.0	0.000400	20.8	24.0	1.54
24	20.1	404.0	0.000317	26.2	30.2	1.22
25	17.9	320.0	0.000252	33.0	38.1	0.970
26	15.9	254.0	0.000200	41.6	48.1	0.769
27	14.2	202.0	0.000158	52.5	60.6	0.610
28	12.6	160.0	0.000126	66.2	76.4	0.484
29	11.3	127.0	0.0000995	83.5	96.4	0.384
30	10.0	101.0	0.0000789	105.0	122.0	0.304
31	8.9	79.7	0.0000626	133.0	153.0	0.241
32	8.0	63.2	0.0000496	167.0	193.0	0.191
33	7.1	50.1	0.0000394	211.0	244.0	0.152
34	6.3	39.8	0.0000312	266.0	307.0	0.120
35	5.6	31.5	0.0000248	336.0	387.0	0.0954
36	5.0	25.0	0.0000196	423.0	489.0	0.0757
37	4.5	19.8	0.0000156	533.0	616.0	0.0600
38	4.0	15.7	0.0000123	673.0	777.0	0.0476
39	3.5	12.5	0.0000098	848.0	980.0	0.0377
40	3.1	9.9	0.0000078	1070.0	1240.0	0.0299

22. Calculation of Voltage Drop.—The resistance of any conductor is given by

$$R = \frac{rl}{A}$$

in which r is the resistance of a wire of unit length and unit cross section (these units are usually one foot and one circular mil), l is the length of the conductor in feet, and A its cross section in circular mils. For copper conductors at a temperature of 25 deg. C. or 77 deg. F., r is 10.5 ohms. By Ohm's law, $R = \frac{E_r}{I}$, in which E_r is the voltage drop when a current of I amperes is flowing. Substituting $\frac{E_r}{I}$ for R we have $\frac{E_r}{I} = \frac{10.5l}{A}$, and $E_r = \frac{10.5Il}{A}$. That is, the voltage drop is equal to 10.5 times the product of the current in amperes and length of wire in feet divided by the cross-sectional area of the conductor in circular mils.

The total length of wire in a circuit is usually twice the distance between the point where the energy is generated and where it is utilized. The circuit voltage drop is then

$$E_r = \frac{10.5I \times 2l}{A},$$

where l is the distance one way.

In case the permissible voltage drop and current are known, then the size of wire that may be used is obtained by solving the above equation for A, thus

$$A = \frac{10.5 \times 2l}{E_r}$$

Again it may be desirable to know the permissible current for a given line drop. Solving for I we have

$$I = \frac{AE_r}{21l}$$

In a similar manner the length of wire for a given line drop and size of wire is given by

$$2l = \frac{AE_r}{10.51}$$

The length of circuit is plainly

$$l = \frac{AE_r}{21I}$$

The total current in a circuit may be found by adding the watts consumed at each outlet and dividing this sum by the prescribed voltage at each outlet. Thus

$$I = \frac{\text{Watts}}{\text{volts}}$$

The line drop E_r is always some proportionate part of the line voltage E, and the ratio $\frac{E_r}{E}$ may be expressed as a percentage of the line voltage. Thus line voltage

$$p = \frac{E_r}{E} \times 100, \text{ whence } E_r = \frac{pE}{100}$$

Sometimes it is desirable to determine the proper size of wire in terms of the power transmitted. This can readily be done as follows: In d.-c. circuits the power is given by

$$W = I \times E$$

But

$$A = \frac{10.5 \times 12l}{E_r}$$

Hence

$$A = \frac{10.5 \times I \times E\,2l}{E_r \times E} = \frac{10.5 \times W2}{E_rE}$$

If the power W is expressed in kilowatts, it will have to be multiplied by 1000 to reduce it to watts before substituting in above equation. For convenience of reference the foregoing formulas are collected together as follows:

$$R = \frac{E_r}{I} \qquad (1)$$

$$E_r = \frac{10.5I \times 2l}{A} \qquad (2)$$

$$A = \frac{10.5I \times 2l}{E_r} \qquad (3)$$

$$I = \frac{AE_r}{10.5 \times 2l} \qquad (4)$$

$$2l = \frac{AE_r}{10.5I} \qquad (5)$$

$$l = \frac{AE_r}{21I} \qquad (6)$$

$$E_r = \frac{pE}{100} \qquad (7)$$

$$A = \frac{10.5W \times 2l}{E_rE} \qquad (8)$$

The letters in the above formulas have the following significance:

A = size of wire in circular mils.
E = voltage of circuit.
E_r = line drop in volts (voltage drop) due to resistance.
I = current flowing in wire in amperes
l = length of circuit or line (one wire) in feet.
$2l$ = total length of wire in feet.
p = voltage drop in per cent of line voltage.
R = resistance of wire in ohms.
W = total watts delivered.

Illustrative Problem.—Given a current of 125 amperes and a line drop of 8 volts, determine the resistance of the line.

$$R = \frac{E_r}{I} = \frac{8}{125} = 0.064 \text{ ohm}$$

Illustrative Problem.—A circuit 400 ft. long is composed of No. 8 wire; what will be the drop when 50 amperes are flowing through the circuit?

The cross-sectional area of No. 8 A. W. G. wire is 16,500 mils. Then by Formula (2)

$$E_r = \frac{10.5I \times 2l}{A}$$
$$= \frac{(10.5)(50)(2)(400)}{16,500}$$
$$= 25.5 \text{ volts, nearly.}$$

Illustrative Problem.—What should be the cross-sectional area of the wire in the preceding problem if the voltage drop is 13.1 volts?

$$A = \frac{10.5I \times 2l}{E_r}$$
$$= \frac{(10.5)(50)(2)(400)}{13.1}$$
$$= 32,100 \text{ cir. mils, nearly.}$$

Illustrative Problem.—What current may be delivered over a line one mile long consisting of No. 00 A. W. G. wire in order that the drop shall not exceed 15 volts? The cross section of No. 00 wire is 133,000 cir. mils.

$$I = \frac{AE_r}{10.5 \times 2l}$$
$$= \frac{(133,000)(15)}{(10.5)(2)(5280)}$$
$$= 18 \text{ amperes, nearly.}$$

Illustrative Problem.—What is the maximum length of circuit that can be made with a No. 000 A. W. G. copper wire allowing a drop of 25 volts with a current of 75 amperes? The cross section of No. 000 wire is 168,000 cir. mils.

$$= \frac{AE_r}{21I}$$
$$= \frac{(168,000)(25)}{(21)(75)}$$
$$= 2666 \text{ ft.}$$

Illustrative Problem.—Given a line voltage of 600 volts, what is the smallest wire that may be used for a circuit of 1000 ft. in length, to carry 60 amperes at a 10 % line loss?

$$E_r = \frac{pE}{100}$$
$$= \frac{(10)(600)}{100}$$
$$= 60 \text{ volts}$$
$$A = \frac{10.5\, I \times 2l}{E_r}$$
$$= \frac{(10.5)(60)(2)(1000)}{60} = 21{,}000 \text{ cir. mils}$$

The smallest wire that would be used is No. 6 A. W. G. which has a cross section of 26,300 cir. mils.

Illustrative Problem.—A two-wire feeder must carry 40 kw. a distance of 400 ft. with a loss of 5 %, the voltage between conductors being 110 volts. Find the size of conductor.

$$E_r = \frac{pE}{100}$$
$$= \frac{(5)(110)}{100} = 5.5 \text{ volts}$$
$$A = \frac{10.5\, W \times 2l}{E_r E}$$
$$= \frac{(10.5)(40{,}000)(2)(400)}{(5.5)(110)} = 555{,}000 \text{ cir. mils.}$$

23. Center of Distribution.—When service wires of uniform size are to be used for conveying energy to a group of scattered lamps, the size of wire for a prescribed voltage drop and number of lamps may be determined by computing the distance L to the center of distribution of the group of lamps from the feeders, by the formula

$$L = \frac{al_1 + bl_2 + cl_3 + \text{etc.}}{a + b + c + \text{etc.}}$$

a, b, c, etc., are the numbers of lamps in each group and l_1, l_2, l_3, etc., are the distances of the groups from the service point.

Illustrative Problem.—What is the distance of the center of distribution from the service point for the groups of lamps 125, 140 and 175 ft. from the service outlet, the first group consisting of 50 lamps, the second of 45 lamps and the third of 30 lamps?

$$L = \frac{al_1 + bl_2 + cl_3}{a + b + c}$$

$$a = 50,\ b = 45,\ c = 30.\quad l_1 = 125,\ l_2 = 140,\ l_3 = 175.$$

Hence

$$L = \frac{(50)(125) + (45)(140) + (30)(175)}{50 + 45 + 30}$$
$$= 142.4 \text{ ft}$$

Illustrative Problem.—What must be the size of service wires if the voltage drop is not to exceed 4 volts when all the lamps are turned on, each lamp taking 0.5 ampere?

$$A = \frac{10.5 I 2l}{E_r} \quad I = (0.5)(125) = 62.5 \text{ amperes} \quad l = 142.4 \text{ ft.} \quad E_r = 4 \text{ volts}$$

Then

$$A = \frac{(10.5)(62.5)(2)(142.4)}{4} = 46{,}725 \text{ cir. mils.}$$

24. Parts of a Circuit.—In Fig. 9 are shown the different parts of a distribution or supply circuit. The connection between the point of supply and the energy-consuming device is made by means of feeders, mains and branches. The feeder is the part of the circuit that extends from the switchboard to the first distributing center. The mains are the supply lines extending from the first distributing center to panel boxes or secondary distributing centers, and branches or branch lines are the parts of the circuit connecting the individual lamps or motors to the distributing centers.

25. Wiring Methods.—The wiring methods commonly used may be considered under two heads, concealed and open. The methods employed in concealed wiring are (1) rigid conduit, (2) flexible conduit, (3) armored cable, (4) knob and tube.

25a. Rigid Conduit.—For interior wiring, electrical conduit is mild steel pipe. This is connected by means of suitable couplings and is installed so as to make a continuous

wire-way from outlet to outlet. Wires are drawn into these after the building is completed. The conduit may be run exposed, or concealed in the walls, between floors, or in channels during construction. The conduit system may be used in any kind of building, but it is used chiefly in buildings of fireproof construction. In fact, no other should be allowed in such buildings. Rules governing the installation of rigid conduit and for grounding the same are found in the

Size of Conduits for the Installation of Wires and Cables. Two-wire and Three-wire Systems

Size of wire	Number of wires in one conduit								
	1	2	3	4	5	6	7	8	9
	Minimum size of conduit, inches								
14	½	½	½	¾	¾	1	1	1	1
12	½	½	¾	¾	¾	1	1	1	1¼
10	½	¾	¾	1	1	1	1¼	1¼	1¼
8	½	¾	1	1	1	1¼	1¼	1¼	1¼
6	½	1	1¼	1¼	1½	1½	2	2	2
5	¾	1¼	1¼	1¼	1½	2	2	2	2
4	¾	1¼	1¼	1½	2	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1½	1½	2	2	2½	2½	2½
1	¾	1½	1½	2	2	2½	2½	3	3
0	1	1½	2	2	2½	2½	3	3	3
00	1	2	2	2½	2½	3	3	3	3½
000	1	2	2	2½	3	3	3	3½	3½
0,000	1¼	2	2½	2½	3	3	3½	3½	4
200,000 C. M	1¼	2	2½	2½	3	3	3½	3½	4
225,000	1¼	2½	2½	3	3	3½			
250,000	1¼	2½	2½	3	3	3½			
300,000	1¼	2½	3	3	3½	3½			
350,000	1¼	2½	3	3½	3½	4			
400,000	1¼	3	3	3½	4	4			
450,000	1½	3	3	3½	4	4½			
500,000	1½	3	3	3½	4	4½			
550,000	1½	3	3½	4	4½	5			
600,000	2	3	3½	4	4½	5			
650,000	2	3½	3½	4					
700,000	2	3½	3½	4½					
750,000	2	3½	3½	4½					
800,000	2	3½	4	4½					
850,000	2	3½	4	4½					
900,000	2	3½	4	4½					
950,000	2	4	4	5					
1,000,000	2	4	4	5					
1,100,000	2½	4	4½	6					
1,200,000	2½	4½	4½	6					
1,250,000	2½	4½	4½	6					
1,300,000	2½	4½	5	6					
1,400,000	2½	4½	5	6					
1,500,000	2½	4½	5	6					
1,600,000	2½	5	5	6					
1,700,000	3	5	5	6					
1,750,000	3	5	5	6					
1,800,000	3	5	6	6					
1,900,000	3	5	6						
2,000,000	3	5	6						

For Stage Pocket, Border Circuits, and Elsewhere By Special Permission

Size of wire	Maximum number of wires in conduit					
	1 in	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.	2 in.	$2\frac{1}{2}$ in.	3 in.
14	11	19	26	43	61	95
12	..	15	21	34	50	77
10	..	12	16	27	38	60
8	..	.	13	22	31	49
6	..	..	.		11	22

National Electrical Code. It may be proper to mention, however, that the two wires of the same circuit should always be drawn into the same conduit. This is especially important when the energy or current supplied is alternating. Experience has shown what size conduit is best suited for the installation of certain size conductors. The following table contains this data in tabulated form. Sections of rigid conduits are shown in Fig. 10.

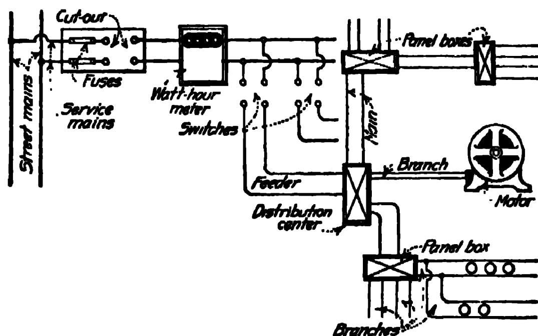


Fig. 9.

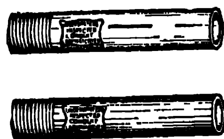


Fig. 10.

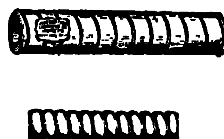


Fig. 11.

25b. Flexible Conduit.—Flexible tubes are made from metal or non-metallic material. To distinguish between the two, it is customary to designate the former by the term flexible conduit, and the latter by flexible tubing (Fig. 11). Flexible conduit is made by winding together spirally two metal strips in such a manner that they interlock at the edges forming a smooth and comparatively frictionless surface inside and out. Single strip flexible conduit is also on the market. The advantages claimed for this metal tube are flexibility, continuity, mechanical, strength and ventilation.

For sizes not greater than No. 10 B. & S. gage, one more conductor than permitted by the above table may be installed in the specified conduit, provided the conduit is not longer than 30 ft., and has not more than the equivalent of two quarter bends from outlet to outlet, the bends at the outlets not being counted.

THREE-CONDUCTOR CONVERTIBLE SYSTEM

Size of conductors	Size conduit, in.
B. & S. gage	Electrical trade size
two 14 and one 10	3/4
two 12 and one 8	3/4
two 10 and one 6	1
two 8 and one 4	1
two 6 and one 2	1 1/4
two 5 and one 1	1 1/4
two 4 and one 0	1 1/2
two 3 and one 00	1 1/2
two 2 and one 000	1 1/2
two 1 and one 0,000	2
two 0 and one 250,000	2
two 00 and one 350,000	2 1/2
two 000 and one 400,000	2 1/2
two 0,000 and one 550,000	3
two 250,000 and one 600,000	3
two 300,000 and one 800,000	3
two 400,000 and one 1,000,000	3 1/2
two 500,000 and one 1,250,000	4
two 600,000 and one 1,500,000	4
two 700,000 and one 1,750,000	4 1/2
two 800,000 and one 2,000,000	4 1/2

NOTE.—Where special permission has been given the following table may apply.

SINGLE CONDUCTOR COMBINATION

No. of wires	Size conduit, in. Electrical trade size
10 No. 14 R. C. solid......	1
18 No. 14 R. C. solid	1 1/4
24 No. 14 R. C. solid	1 1/2
40 No. 14 R. C. solid	2
74 No. 14 R. C. solid	2 1/2
90 No. 14 R. C. solid	3

The flexibility of the conduit permits its use in many places where the use of rigid conduit is impractical. On this account it is used mostly in buildings where it is desired to run electric circuits after the completion of the building.

Where the first cost of an installation must be kept at a minimum, and yet where a safe and more permanent wiring than the knob and tube system is required, the flexible conduit may be advantageously used.

The same rules govern the installation of flexible conduit that apply in the case of rigid conduit.

25c. Armored Cable.—The casing of an armored cable is very similar to the flexible conduit just explained. Steel armored cable is distinguished from flexible conduit by having the conduit made over the conductors so that both conduit and conductors may be installed at the same time. Fig. 12 shows the general appearance of such a cable. In certain cases, specified in the code, the cable must have a lead covering placed between the outer braid of the conductors and the steel armor.

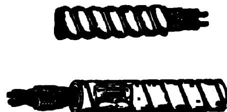


FIG. 12.

25d. Flexible Tubing.—Flexible tubing is distinguished from flexible conduit in that the tube is made of fibrous material. Flexible tubing is used mainly in conjunction with knob and tube work in places where the knobs or tubes do not furnish sufficient protection and where the rules require additional safeguards. As a separate method of wiring, the flexible tube is very little used, and its use in place of the other methods mentioned should be discouraged.

25e. Knob and Tube Wiring.—The most common method of wiring for frame buildings during the process of construction is the knob and tube method. As the name indicates, the wires are run on knobs, and where they pass through timbers, additional insulation is provided by porcelain tubes. In this method of wiring the conductors are run concealed between floors and partitions; when the conductors run parallel to the joists and in vertical runs, knobs attached to the timbers by screws, or nails and leather heads are used; and where the conductors pass through partitions or timbers, tubes are first inserted. Fig. 13 shows the general appearance of a knob and tube installation.

Solid knobs were formerly used exclusively but have been almost entirely displaced by split knobs such as are shown in Fig. 14, in which is also shown a porcelain tube and cleat.

26. Protection of Circuits.—The energy is supplied to the building by two- or three-wire service mains. At the point of entrance, or as near as possible at the point of entrance, and inside of the walls, automatic cut-outs must be installed and arranged, to cut off the entire

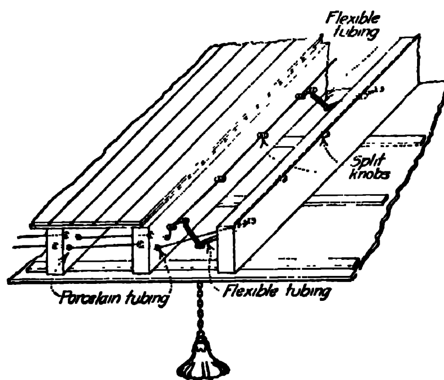
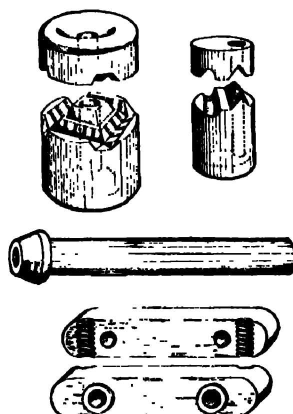


Fig. 13.


Fig. 14.

current from the building. These cut-outs may be fuses or automatic circuit breakers. The kind of cut-out to install in any case will depend upon the load supplied. The rated capacity of fuses must not exceed the allowable current carrying capacity specified in table on p. 1296. Circuit breakers must not be set for more than 30% above the allowable carrying capacity of the wire unless a fusible cut-out is also installed in the circuit.

27. Fuses.—A fuse is a relatively short piece of wire or conductor, of relatively low melting point, whose current carrying capacity is less than that of the circuit in which it is placed. By combining tin, bismuth, and lead in proper proportions, it is possible to make alloys which will melt at low temperatures. Wires on strips made from these alloys are soldered between copper terminals and used for fuses. The greater the current carrying capacity of the fuse, the longer is the time required for its operation at a given overload.

In selecting the proper size of fuses to protect any apparatus, the time element, as explained above, should be considered in connection with the smallest current likely to prove dangerous.

Since all motors are required to carry momentary overloads, fuses with a comparatively long-time lag are well suited for their protection. The capacity of the fuse is usually equal to the full-load current of the motor, and the momentary overload of 50% will not open the fuse nor will it do any damage to the motor. If the overload continues, the fuse will open the circuit before any damage can be done to the motor.

For protecting alternating-current motors, fuses are not so well adapted. The reason for this is that the alternating-current motors take excessive current on starting. When the motor has reached full speed, the current is very much reduced. Thus, fuses whose current-carrying capacity is equal to the full-load current, will open

the circuit upon starting and, if the capacity of the fuse is sufficiently large to carry the starting current, it will not protect the motor in case of a long-continued overload. One way of overcoming this difficulty is to use two sets of fuses in parallel; one set of fuses having a capacity equal to the starting current and the other equal to the running current. Each set of fuses should be cut in or out by means of a separate switch. On starting, the switch in series with the "running" set of fuses should be open, and closed after the motor has come up to speed, when the other switch is opened. When such an arrangement is used, a much better protection is given to the motor.

Fuse and Wire Sizes for Induction Motors of Squirrel-cage Type or Similar Types Taking Large Starting Currents

INDUCTION MOTORS—SINGLE PHASE—All Frequencies and Standard Speeds

Hp.	Full load amps				Starting fuse amps.				Running fuse amps.				Size of wire or cable. Rubber or other insulation			
	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.
0.5	6.8	3.4	1.7	1.3	20	10	5	5	10	5	5	5	14	14	14	14
1.0	13.3	6.6	3.3	2.4	35	20	10	5	15	10	5	5	8	14	14	14
2.0	24.8	12.4	6.2	4.9	65	35	20	15	30	15	10	5	6	8	14	14
3.0	36.0	18.0	9.0	7.2	75	45	30	25	40	20	15	10	4	8	10	12
5.0	58.4	29.2	14.6	13.8	120	70	40	30	65	35	20	15	2	6	8	10
7.5	85.2	42.6	21.3	17.1	170	85	55	45	95	45	25	20	0	4	6	8
10.0	110.0	55.0	27.5	22.4	220	110	70	60	120	60	30	25	00	2	6	6
15.0	162.0	81.0	40.5	33.0	325	165	80	70	180	90	45	35	211,600	0	4	6
20.0	208.0	104.0	52.0	42.6	400	200	110	85	230	115	60	45	300,000	0	2	4
25.0	258.0	129.0	64.5	51.6	500	260	135	100	280	140	70	60	400,000	000	1	2
30.0	304.0	152.0	76.0	61.0	600	300	150	125	335	170	85	70	500,000	200,000	0	2
35.0	356.0	178.0	89.0	70.0	710	360	180	140	380	190	100	80	650,000	300,000	0	1
40.0	400.0	200.0	100.0	80.0	800	400	200	160	440	220	110	90	750,000	300,000	0	0
50.0	492.0	246.0	123.0	99.6	980	590	250	200	540	270	135	110	1,000,000	500,000	000	0

INDUCTION MOTORS—TWO PHASE—FOUR WIRE—All Frequencies and Standard Speeds

Hp.	Full load amps.*				Starting fuse amps.				Running fuse amps.				Size of wire or cable. Rubber or other insulation			
	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.
0.5	3.1	1.5	0.8	0.6	10	5	5	5	5	5	5	5	14	14	14	14
1.0	6.0	3.0	1.5	1.1	15	10	5	5	10	5	5	5	14	14	14	14
2.0	11.0	5.6	2.8	2.2	30	15	10	5	15	10	5	5	10	14	14	14
3.0	14.7	7.3	3.6	3.2	40	25	15	10	20	10	5	5	8	10	14	14
5.0	28.6	14.3	7.1	5.3	70	35	20	15	30	20	10	10	6	8	12	14
7.5	38.8	19.4	9.7	7.8	80	50	30	20	45	25	15	10	4	8	10	12
10.0	50.2	25.1	12.5	10.8	100	65	35	30	55	30	15	15	2	6	8	10
15.0	73.4	36.7	18.3	15.0	150	75	45	40	80	40	20	20	1	4	8	8
20.0	95.0	47.5	23.7	19.5	190	95	60	50	110	50	30	25	0	2	6	8
25.0	118.0	59.0	29.5	23.4	240	120	70	60	130	65	35	30	000	2	6	6
30.0	138.0	69.0	34.5	27.6	280	140	75	65	150	75	40	30	200,000	1	4	6
35.0	162.0	81.3	40.5	32.0	320	160	80	70	190	90	45	35	211,600	0	4	6
40.0	182.0	91.0	45.5	36.4	360	180	90	75	200	100	50	40	300,000	0	4	4
50.0	224.0	112.0	56.0	45.0	450	225	110	90	245	125	60	50	350,000	00	2	4
60.0	268.0	134.0	67.0	53.5	540	270	135	110	290	150	75	60	450,000	000	1	2
75.0	332.0	166.0	83.0	66.5	660	330	170	130	365	180	90	75	600,000	211,600	0	1
100.0	.....	218.0	109.0	87.5	....	440	220	175	....	240	120	95	....	350,000	00	0
150.0	.....	320.0	160.0	128.0	....	640	320	260	....	350	175	140	....	550,000	211,600	000
200.0	.....	418.0	209.0	169.0	....	830	420	340	....	450	230	185	....	800,000	350,000	300,000
250.0	.....	515.0	257.0	207.0	...	1030	500	400	....	560	280	230	....	1,100,000	400,000	300,000
300.0	.....	615.0	307.0	246.0	...	1230	600	500	...	675	340	270	....	1,400,000	500,000	400,000

* Value of current in common wire for a two-phase three-wire system would be 1.41 times value given.

INDUCTION MOTORS—THREE PHASE—All Frequencies and Standard Speeds

H.p.	Full load amps.				Starting fuse amps				Running fuse amps				Size of wire or cable. Rubber or other insulation			
	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.	110 V.	220 V.	440 V.	550 V.
0.5	3.6	1.8	0.9	0.7	10	5	5	5	10	5	5	5	14	14	14	14
1.0	7.0	3.5	1.75	1.3	20	10	5	5	10	5	5	5	14	14	14	14
2.0	13.0	6.5	3.25	2.6	30	20	15	10	15	10	5	5	10	12	14	14
3.0	19.0	9.5	4.75	3.8	50	30	20	10	25	15	10	5	8	10	14	14
5.0	30 8	15.4	7.7	6.2	70	40	25	15	35	20	10	10	6	8	12	14
7.5	44.8	22.4	11.2	9.0	90	60	30	25	50	25	15	15	4	6	10	12
10.0	58.0	29.0	14.5	11.8	120	70	40	30	65	35	20	15	2	6	8	10
15 0	85.0	42.5	21.2	17.4	170	85	50	40	95	45	25	20	0	4	8	8
20.0	110.0	55.0	27.5	22.5	220	110	60	55	120	60	30	25	00	2	6	6
25.0	136.0	68.0	31.0	27.0	270	140	70	65	150	75	40	30	000	1	6	6
30.0	160.0	80.0	40.0	32.0	320	160	80	70	175	90	45	35	211,600	0	4	6
35.0	188.0	94.0	47.0	37.0	375	190	100	75	210	110	50	10	300,000	0	2	4
40.0	210.0	105.0	52.5	42.0	420	210	110	85	230	115	60	45	350,000	00	2	4
50.0	260.0	130.0	65.0	52.0	520	260	125	110	285	115	70	60	450,000	000	1	2
60.0	310.0	155.0	77.5	62.0	620	310	160	125	340	170	85	70	550,000	211,600	0	2
75.0	384.0	192.0	86.0	77.0	770	390	175	160	420	210	95	85	750,000	300,000	0	0
100.0	.....	252.0	126.0	101.0	....	500	250	200	....	280	140	110	....	400,000	000	0
150.0	.....	368.0	184.0	148.0	....	730	370	300	....	410	200	160	......	700,000	300,000	200,000
200.0	.....	484.0	242.0	195.0	....	920	480	390	....	530	265	215	.....	900,000	400,000	300,000
250.0	.....	595.0	287.0	240.0	....	1200	570	480	....	650	315	265	....	1,300,000	500,000	400,000
300.0	.....	710.0	355.0	285.0	...	1420	710	570	....	780	390	315	...	1,600,000	650,000	500,000

The tables given above prepared by a committee of the Western Association of Electrical Inspectors give the horsepower rating, full-load current, size of starting fuses, and sizes of wire for alternating-current motors of the induction type of all frequencies, standard speeds and standard volt ages. Rules of the National Electrical Code were taken into account in the preparation of these tables. The assumption is made that the motors are to be started under full load and that starting devices are used on motors larger than 5 hp. The question of voltage drop has not been taken into consideration.

A standard guarantee of 25 % overload for 2 hr. has been adopted by the American Motor Manufacturers' Association and this excess current should be taken care of in the design of leads and auxiliary apparatus for motors. Some motors used for intermittent service require an overload capacity of 200 % for a short period of time and the motors should be fused accordingly. For ordinary motors coming under the above-mentioned guarantee, fuses rated at 25 % above the normal full-load current of the motor should be used which will insure the opening of the circuit at approximately 50 % overload. Fuses rated at 60 % more than the normal 30-min. current rating should be used on motors of intermittent rating, such as variable speed motors.

27a. Enclosed Fuses.—The first enclosed fuse was that designed by Edison some 30 years ago. In its present form the Edison plug fuse, as it is called, consists of a hollow porcelain plug on the lower outside part of which is a threaded brass ring. One end of the fuse wire is fastened to this ring and the other end passes through the bottom of the plug and is soldered to a small brass cap. To prevent the escape of the hot metal when the fuse blows, the plug is closed by a piece of mica held in place by a brass ring. The rating of the fuse is marked both on the small cap at tip of plug and on the ring which holds the mica in place. The appearance of this type of enclosed fuse is shown in Fig. 15. Although this plug was brought out some 30 years ago, it is undoubtedly used to a greater extent today than any other form of enclosed fuse, especially on house lighting circuits.

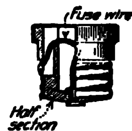


Fig. 15.

27b. Cartridge Fuses.—When the 220-volt system came into use, it was soon discovered that the operation of the Edison plug fuse was very unsatisfactory and the enclosed cartridge fuse was designed. The cartridge fuse consists of a piece of zinc-aluminum fuse wire enclosed in an insulating tube, usually of vulcanized fiber, paper or similar material. The fuse wire is surrounded by an inert, nonconducting material resembling chalk. The ends of the

fuse are attached to copper caps which fit over the ends of the fiber tube. Fig. 16 shows the arrangement of the various parts. When a fuse of this type is blown, the formation of an arc is prevented by the filling within the tube. In most cases, this prevention is purely mechanical, but in some makes of cartridge fuses, there is a chemical action between the filling material and melted fuse; in other cases a small air chamber surrounds the fuse wire, as shown in Fig. 16. Experience and tests have shown that the cartridge type of fuse is far more accurate and fuses melt more nearly at the proper point than any other type of fuse. Some other advantages are its ease in manipulation, range of voltage, and freedom from the influence of air currents.

Standard dimensions and test requirements have been prepared for 250- and 600-volt fuses. These requirements are given in the National Electric Code. The dimensions of fuses have been carefully worked out and are as small as it is safe to make them. Standard fuses are now made by all principal fuse manufacturers and are interchangeable in all National Electric Code standard fuse blocks of corresponding capacity. The use of fuses of special dimensions and particularly those smaller than the standard should be discouraged.

The National Code divides enclosed fuses into classes according to the voltage and ampere capacity and specifies the dimensions for each class so that a given fuse can be used only in a fuse block of its class. The fuses are rated so that they will carry 10 % overload indefinitely and will open at 25 % overload.

The ferrule contact is used on fuses up to 60 amperes capacity and knife-blade contacts are those of larger capacity. Fig. 17 shows fuse blocks of different forms.



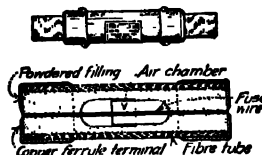
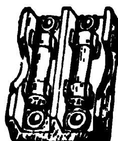
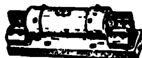


Fig. 16.





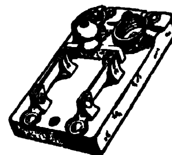


Fig. 17.

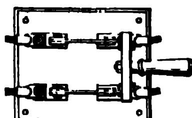
28. Switches.—Switches may be classified in various ways. If the voltage is taken as the basis of classification, we have the low-voltage and high-voltage switches. With reference to their construction and operation they may be classified as knife, snap, push button; if the basis of our classification is the number of line wires that can be opened and closed by the opening and closing of the switch, we have the single-pole, double-pole, triple-pole, etc., switches. Again switches may be single throw (S. T.) and double throw (D. T.) depending upon the number of ways in which they can be closed. The distinction between knife, snap, and push button switches needs no extended discussion. Single-pole, double-pole, and triple-pole switches are distinguished from each other by the number of line wires that can be opened or closed at once. Thus a single-pole switch can be used in only one wire of a circuit; a two-pole, in two wires; a three-pole, in three wires. Single-pole, double-pole, and three-pole switches are represented in Figs. 18, 19, and 20 respectively. A double-pole double-throw switch is shown in Fig. 21. A double-pole double-throw switch differs from a single-throw switch in that two circuits may be successively connected by it to the same supply circuit, or if cross connected, the direction of the current may be reversed. Snap and push button switches are made both single and double pole, but never double throw. Knife switches must be installed in such a manner that gravity will not tend to close the switch, and both switch and receiving circuit must be protected by fuses or some other form of "cut-out." The switch should be so connected that when it is open the blades are dead. A good method of connecting a service switch to the line is shown in Fig. 22. The figure shows Edison plug fuses in the mains. It is also clear that when the switch is opened, the blades are disconnected from the mains and can safely be handled. It is advisable to connect a knife switch in this manner whenever possible. Some knife switches are provided with an extra set of jaws to which the line circuit is connected. On such a switch the hinge joints are never connected to the circuit.

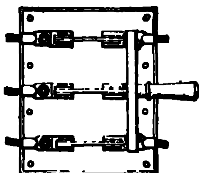
Mention was made above of the possibility of controlling lights from two points by means of three-way switches. The manner in which this is done will perhaps be understood best by reference to Fig. 23. This is a standard diagram for three-way switch connection. Assuming the switches to be turned as indicated by full lines—that is, 2

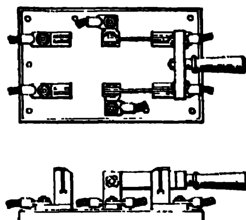
being connected to 4 and 2′ to 4′—no current can flow through the lamps. If either switch be turned so that either 1 and 3 or 1′ and 3′ are connected, the lamps will light, and then turning either switch again will disconnect them. Three-way switches are considered as single-pole switches and must be wired so that only one pole of the circuit is carried to either switch.

If it is desired to control the lights from more than two points, a four-way switch must be used at each additional point. A diagram of connections is shown in Fig. 24. If the switches are turned as indicated in diagram, the lamps will be dark. Turning either switch will cause them to light up. Three-way and four-way switches are much used in house wiring, especially for controlling the lighting of stairways and upper and lower halls.


Fig. 18.


Fig. 19.


Fig. 20.


Fig. 21.

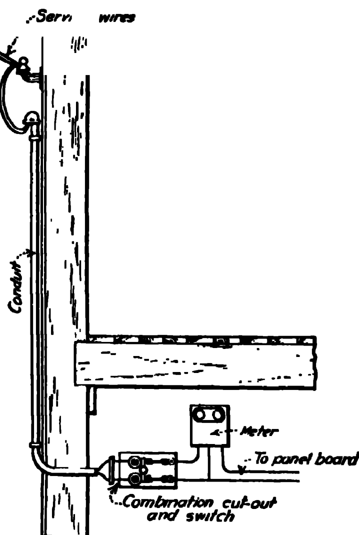


Fig. 22.

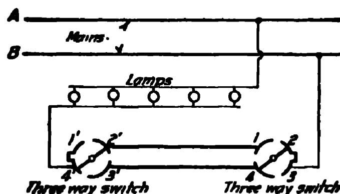


Fig. 23.

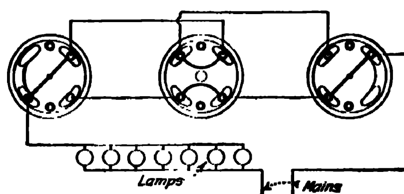


Fig. 24.

28a. Electrolier Switch.—This is a form of snap switch which is designed for closing one or more circuits. A diagram of the internal connections of a three-circuit electrolier switch is given in Fig. 25. The first quarter turn of the handle, lights the lamps connected at 1; the second quarter turn, those at 1 and 2; and the third quarter turn, all the lamps. The fourth quarter turn opens the circuit. It is not possible to illustrate the operation with a simple diagram.

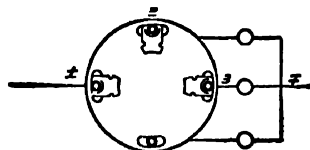


Fig. 25.

29. Cut-out Panels and Cabinets.—According to the Electrical Code not more than 660 watts, or under special conditions, not more than 1320 watts for lighting circuits may be supplied through one cut-out. This necessitates many branch circuits for all installations except the smallest. It is usually most convenient to group the cut-outs together and mount them on panel boards (Fig. 26). They are made in many forms and for two-wire and three-wire circuits. The bus-bars are usually run vertically with the cross-connecting bars extending horizontally to the branch circuits. These horizontal bars are interrupted for fuses, or for both switches and fuses.

Three forms of fuses are used at the present time for the panel board type of cut-out; i.e., the plug fuse, the link fuse, and the enclosed or cartridge fuse.

For conductors smaller than No. 8 A W.G. the connection is made by means of binding screws with copper washers. This connections is used for all the branch conductors which are usually of No. 14 or No. 12 wire, although in a few cases No. 10 conductors are used. When conductors of No. 8 or larger are used, the connections are made by means of special copper lugs, the wires being inserted in a hole in the lug and soldered. Such a connection is a marked improvement over the method of screws and washers. Where the wire is held in place by a screw and washer, only a small portion of the wire is in actual contact, and overheating at the terminal may result. The lug terminal is preferable in nearly all cases, as it provides a good and lasting connection. A solid wire larger than No. 8 is very stiff and vibrations will loosen it if secured under a binding screw and washer.

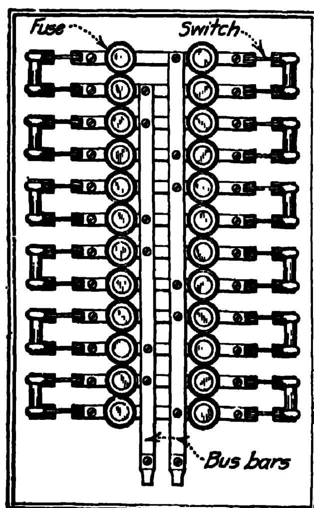


Fig. 26.

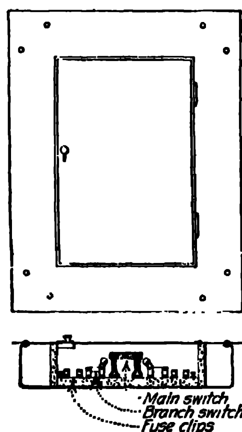
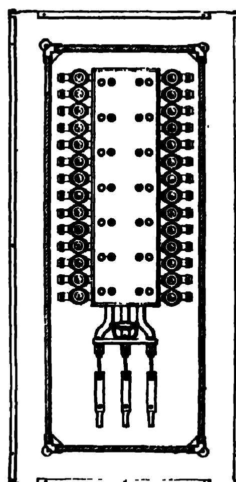


Fig. 27.


Fig. 28.

For purposes of protection and convenience in operation, panel boards are mounted in cabinets (Fig. 27).

In department stores or buildings where lights are thrown on and off by means of switches at the panel board, and where persons unskilled in the uses of electricity operate the switches, panel boards should be designed so as to prevent access to the interior of the cabinet. This is readily accomplished by using push-button switches in the branch circuits. The push-button switches can be made flush with the door of the cabinet, which may be locked, or the switch compartment may be provided with a separate door. By the latter arrangement it is possible to lock the fuse compartment and provide latches for the switch compartments (Fig. 28).

For the use of unskilled persons the push-button switch is preferable to the knife switch. A novice in electrical matters is very apt to close or open the circuit slowly which causes arcing and may ruin the switch. This cannot happen when push-button or snap switches are used as the mechanisms operate with a quick make-and-break.

30. Outlet Boxes.—Metal outlet boxes are required at all outlets where conductors are run in conduits or armored cables, and for flush switches and receptacles in connection with any kind of covering.

Outlet boxes are not required by the present rules for circuit work run in wooden molding for cleat work, or for knob and tube wiring, except as noted above.

All the principal forms of outlet boxes may be roughly classified in two groups, universal and special. Under the first head are included those forms of boxes in which an opening may be made in any part of the box, so that, no matter from what direction the tube comes, a cor-

responding opening in the box may be more or less readily made without drilling. The other type of box is one which is designed for a specific purpose. Fig. 29 is a universal outlet box.

31. Distributing Systems.—In any system of wiring the supply circuit terminates at either a cut-out cabinet or a switchboard. From the cabinet or switchboard several sets of feeders and mains are usually run to various points from which the current is supplied to lamps, motors, or to other receiving apparatus.

31a. Selection of a Feeder System.— In every case the arrangement of the feeders will, of course, be determined by the use and arrangement of the receiving apparatus. In house wiring for lighting purposes there are, however, some general conditions which influence the feeder systems. These conditions may be classed under the following heads:

1. Control of groups of lights from main switchboard.
   (a) Hall lights.
   (b) Other than hall lights.
2. The number of outlets that should be supplied by one of feeders.
3. The limit for the size of feeder conductors
4. Allowable loss in feeders and mains

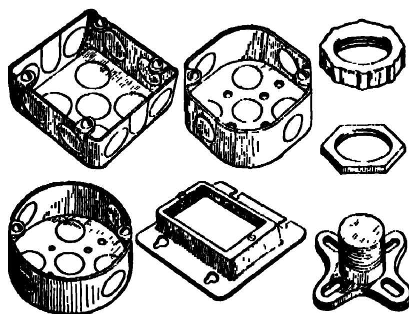


Fig. 29.

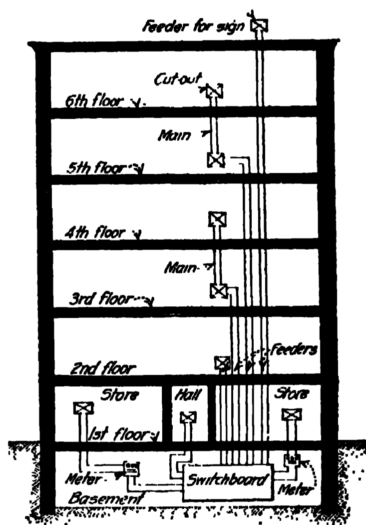


Fig. 30.

In the designing and laying out of feeder systems the use and arrangement of the building must be given due consideration. The control of hall lights from one point, usually the main switchboard, is a matter of considerable importance. This, however, applies primarily to hotels, apartment houses, or to buildings in which the light for halls is furnished by the owner of the building, and therefore, should be under the control of men in his employ.

Control of Hall Lights from One Point.— In private residences it is seldom advisable to have separate feeders for hall lights, since it is much more convenient to operate the lights by switches placed at convenient points in the halls. In public buildings it is almost always advisable to install separate feeders for hall lights. The main point in the problem is not the necessity for separate feeders, but the number necessary for efficient operation. For instance, in lighting long halls it is often necessary to have different numbers of lamps turned on at different times in the day, and also on different days. This, of course, combines the problem of efficient lighting with wiring as is true in almost every case In the solution of such a problem it is necessary to first determine the number and distribution of lamps and the approximate time when these lamps are to be operated. Having determined the number of groups of lamps that are to be operated, the number of pairs of feeders and their current-carrying capacities can then be readily determined. Thus, if it is found that the lights can or should be operated in three groups, three pairs of feeders will be necessary. Each group of lamps can be turned on and off at the proper time without interfering with the others. It is very probable that the cost of the additional feeders will be more than compensated for by saving in energy. A good arrangement of feeder systems for hall lighting is shown in Fig. 30. The necessity for more than one set of feeders arises from the fact that it may not be advisable to have lights burning

on all floors at the same time. The subdivision of feeders into sets may thus effect an appreciable saving in energy.

Control of Other than Hall Lights.—When groups of lights, other than hall lights, are to be controlled from the main switchboard, separate feeders should be provided for each group of lights. This is especially true in case there is some decorative lighting. Lights for decorative purposes should always be controlled from some convenient point.

Before laying out any system of feeders an elevation of the building should first be drawn, and the service required on each floor noted. This does not mean simply the amount of power, but the use and time during which the power is to be used. Having determined this together with the power supply—that is, whether it is the intention to obtain power from the central station or whether a separate plant is to be installed—the contractor can proceed with the laying out of feeders and mains.

While arranging the scheme for feeders and mains, consideration must be given the construction of the building with special reference to runways and shafts which will greatly facilitate the installation of the feeders. The usual scheme followed is first to locate the outlets and then the distributing centers. The main points to be considered are the current density and source of supply.

31b. Greatest Number of Outlets One Set of Feeders May Supply.—There is no absolute rule that can apply in every case concerning the number of outlets that may be supplied by one set of feeders. There are, however, some general considerations which should be kept in mind. Economy and convenience of operation will perhaps be greater if each set of feeders supplied few units. The reasons are: (1) when many units are being fed by one set of feeders a sudden overload may cause an opening of the circuit and a disturbance over a considerable area—that is, any accident that would cause the opening of the circuit connecting that set of feeders with the bus-bars would cause greater inconvenience than if the receiving apparatus were supplied by several feeders; (2) more economical operation will undoubtedly be secured by dividing the load among several sets of feeders.

31c. Limiting Size of Feeder Conductors.—Local conditions will, to a great extent, determine the exact size of feeder conductors in any particular case. If the question of cost is given first consideration, it will be found cheaper to install a conductor whose capacity is large enough to carry the maximum current rather than several smaller ones whose combined capacity is the same. The ease and facility with which the small conductors may be run, will, in many cases, compensate for the difference in cost; and furthermore, the possibility of subdivision should not be overlooked. Conductors larger than 1 in. in diameter should seldom be installed. When a larger current capacity is necessary, it will invariably be found cheaper to run smaller conductors whose capacity in the aggregate is equal to the capacity required.

There are other reasons for using smaller conductors: (1) the available space for running conduits, and (2) the size of conduit itself may restrict the size of feeder conductors. Thus, feeders requiring over 2-in. conduit should never be used since a 2-in. pipe is about as large as can be economically handled especially if there are many bends or offsets.

31d. Allowable Loss in Feeders and Mains.—The exact voltage drop to be allowed in feeders will depend upon the total permissible drop from switchboard to lamps. A good rule is to allow about one-half the total permissible drop for feeders, one-fourth for mains, and one-fourth for branch circuits. Such a division is conducive to good voltage regulation at the lamps.

Since mains are mere extensions of feeders most of the foregoing discussion applies to them as well.

32. The Process of Determining the Size and Quantity of Wire Required for a Given Installation.—The general principles so far discussed may be applied in any particular case as follows: First, prepare a vertical cross section of the building showing the number of stories and their height. Upon this, and upon the floor plans, mark the position of the outlets, and from these the branch circuits, distributing centers, and rising shafts. Upon the elevations and floor plans, mark at each distributing center the number of watts which are to be supplied by the branch circuits, starting from the center. Having done this, a tentative layout of the mains may be made. It is clearly evident that the purpose of the foregoing process is to determine the

current to be carried by each set of mains and feeders. From this data and the allowable drop, the size of conductors may then be calculated.

From the elevation and floor plans, next determine the approximate length of the feeders and mains. This approximate length will be accurate enough for computing the drop and, consequently, the size of conductor.

According to principles already given, the cross-sectional area in circular mils is then

$$A = \frac{10.5P \times 2l}{E_rE}$$

The data for calculating the size of mains is obtained in the same way and the calculations are also made as above. For determining the cost of the conductors the approximate length as given above will not be sufficiently accurate. The actual length as nearly as possible should be determined by the aid of the floor plans and elevation by indicating very nearly the actual direction the wires are to run and making allowance for slack, bends, and offsets. About 5 % of the length is usually allowed for slack, and no definite percentage can be given for bends and offsets. This must be determined from the plans themselves, or in case the framework of the building has already been erected, by actual measurements on the building Before deciding definitely upon a particular scheme, it is well to make the necessary calculations for at least two or more different arrangements. It will often be found that some one plan will be more economical or more easily followed.

33. Specifications.—A specification may be briefly defined as a detailed statement of materials to be used and the manner of executing the work.

Most of the materials for inside electrical construction are at present standardized and must have the approval of the Electrical Committee of the National Fire Protection Association. Consequently, in preparing specifications it is usually unnecessary to go into extended detail when describing the material to be used. For this part of the specifications it will usually be found sufficient to name the types of construction and specify that only approved material may be used. The second part of the specifications—namely, construction and method of control, etc.,- should be worked out with considerable detail. This is especially necessary where the contract for the wiring is to be let to the lowest responsible bidder. If the specifications are not adequate, there can be no comparative basis for letting the contract.

In the preparation of a set of specifications it is important that the language used be grammatical and construed according to the rules of grammar. It is dangerous to permit inaccuracy or confusion in the arrangement of clauses, because the true intent may thus be distorted and not admit of ready interpretation. There are many words and phrases which may have one or several meanings in ordinary narration, but quite different meanings when used in technical description, or in relation to some special subject, and it must be supposed that technical words and phrases are used in the specific and technical sense applicable to the subject.

Specifications for electric wiring that is to be installed under a separate contract should contain in the first paragraph a statement that the work is to be done and the material is to be furnished in conformity with the following: (1) American Institute of Architects' Instructions to Bidders; (2) National Electrical Code; and (3) the Ordinances of the City and Rules of the Inspection Department of the city in which the work is to be done. Consideration should also be given to the requirements of the electricity supply company to secure the best operating and maintenance conditions.

In general, it may be said that in addition to the architect's instructions, the National Electrical Code, and city and inspection department regulations, the specifications should cover in detail: (1) the general considerations applicable to any installation, and (2) a detailed description of the installation in question.

SECTION I. GENERAL CONDITIONS

The general considerations may be subdivided further as follows:

Scope of Contract.—Under this heading should be stated the work to be covered by the specifications.

Explanations.—Under explanations should be enumerated the meaning and force of the specifications, and who shall be the final authority in interpreting the specifications.

Changes.—Under this heading should be enumerated conditions under which changes will be permitted, who shall specify what changes are to be made, and how pay shall be estimated for changes ordered. The following example illustrates this:

"No changes will be permitted in these specifications, or in the plans accompanying the same, except in minor details or for good legitimate cause, or except when made necessary by reason of altered conditions or changes in the building.

"No such changes shall be made without the authority of the representative of the owner.

"The owner shall have the privilege of ordering any changes that may be deemed desirable or necessary, for the hereinabove specified reasons or for other legitimate reasons, at any time before the completion of the work.

"All such changes, involving no additional cost to the Contractor and no loss or expense to the owner, are to be made free of expense to the owner.

"For all changes ordered by the owner, or his representative, the settlement shall be made when possibly by reference to the "stated prices" which are required to be quoted in the Contractor's proposal, as specified hereinafter.

"For any addition to, or omission from, the circuit work, or for any other change required in the installation, involving additional cost to the Contractor, and for which no adequate basis of settlement has been provided in the "stated prices" aforesaid, the Contractor must first give written notice of such additional cost, and must submit an estimate; and a special order shall be issued for the said addition, omission, or change, before the work of making said change is begun.

"Bills of all extra work must be rendered promptly on the completion of said extra work, accompanied with all items, and details necessary for the proper audit of said bills.

"The owner shall receive credit for the value of all materials or work discarded and not installed.

"No allowance shall be made for extra work unless these conditions are fully complied with."

Supervision.—This clause is to specify the individual or official under whose immediate supervision the work is to be executed, and to whom is reserved or given the right to accept or reject any portion of the equipment, and what shall be the criterion for such acceptance or rejection.

Repairs, Defects, Etc.—A paragraph with the above heading is necessary to cover the character of the labor employed by the contractor; the time during which contractor agrees to keep equipment in repair, which may be necessary on account of defective material or workmanship.

Other Trades.—Since in the construction of nearly all buildings, members of several different trades may be employed, it becomes necessary to include a clause explaining the relation between the wiring contractor, owner, and other workmen on the building. It is also necessary to explain under whose direction and supervision work other than the wiring is to be done when the wiring necessitates such work.

Subcontracting.—In order that the owner or his representative may at all times know whom to hold responsible for the performance of any part of the work it is customary to specify conditions under which the whole or parts of the contract may be sublet.

Accidents.—In order to avoid controversy over the responsibility for accidents, it is necessary to state clearly that the contractor and his subcontractors are to bear any loss which may result from their own neglect. This is especially important in states which have industrial laws.

Inspection.—This part of the specifications is usually covered by a clause something like the following:

All materials and work are to conform in all respects to the requirements and regulations of the National Board of Fire Underwriters and any local boards having jurisdiction, including the latest amendments and modifications to their rules. The contract is not to be considered complete until all necessary certificates of inspection have been furnished.

SECTION II. DETAILED SPECIFICATIONS

Plans.—Number of plans and what each covers.

Service Wires.—Location of service wires, and character of wiring.

Lamps and Fixtures.—If the lamps and fixtures are to be a part of the contract, their character and types should be described in detail. It is perhaps better to have a separate set of specifications for this part of the installation.

Feeders and Mains.—Give sizes of wires; state between what points they are to be run, and whether separate circuits are to be run for motors, heating devices, or other accessories.

Branch Circuits.—Describe size of wires to be used for the different circuits.

Conduits.—Kinds of conduits; sizes for feeders and mains; sizes for branch circuits; method of installing; care to be used in fitting.

Outlet Boxes.—Kinds of outlet boxes that will be permitted.

Fixture Supports.—Where to be located and designs to be used.

Cut-out Cabinets.—Where to be located; by whom furnished; kind.

Cut-outs.—Kinds; mounting; style of switches for branch circuits.

Fuses and Fuse Holders.—Kinds; where to be located.

Switches.—Types, locations, capacity, etc.

Baseboard and Wall Receptacles.—Kinds and locations.

General.—Describe any special features that do not properly come under any of the above headings.

Test.—Describe test which is to be applied to make installation acceptable.

SECTION III. WIRING FOR TELEPHONES

This is usually done by the telephone companies, but in order to have the telephone wiring run to proper and convenient outlets, the following may be safely included:

Conduit Run for Telephones.—Location of telephones; systems to be used.

Terminal Boxes.—Where located.

SECTION IV. WIRING FOR ELEVATORS

In buildings where elevators are to be used, specifications for this should be included. The most important items will be:

Kind of Service.
Feeders.
Location of Meter.
Outlets, etc.

The notes following the general headings are merely indicative of what should be described in detail. Where necessary the description should be supplemented by drawings showing any special features or arrangements.

34. Standard Symbols for Wiring Plans.—The National Electrical Contractors' Association and the American Institute of Architects have agreed upon symbols which are to be used in wiring plans and specifications.

This specification is based upon the use of the following standard symbols adopted by the National Electrical Contractors' Association and the American Institute of Architects.

- Ceiling outlet
- Ceiling outlet (gas and electric)
- Ceiling-lamp receptacle
  Specification to describe type such as key, keyless, or pull chain
- Ceiling outlet for extensions
- Ceiling-fan outlet
- P.S. Pull switch
- Drop cord
- Wall bracket
- Wall bracket (gas and electric)
- Wall outlet for extensions
- Wall-fan outlet
- Wall-lamp receptacle
  Specification to describe type such as key, keyless, or pull chain
- Single-convenience outlet
- Double-convenience outlet
- Junction box
- Special-purpose outlet
  Lighting, heating, and power as described in specifications
- Special-purpose outlet
  Lighting, heating, and power as described in specifications
- Special-purpose outlet
  Lighting, heating, and power as described in specifications
- Exit light
- Floor outlet
- E Floor elbow
- T Floor tee
- S^1 Local switch, single pole
- S^2 Local switch, double pole
- S^3 Local switch, three way
- S^4 Local switch, four way
- S^D Automatic door switch
- S^K Key push-button switch
- S^E Electrolier switch
- S^P Push-button switch and pilot
- S^R Remote-control push-button switch
- T.S Tank swtich
- Motor
- M.C Motor controller
- Lighting panel
- Power panel
- Heating panel
- Pull box
- Cable-supporting box
- Meter
- Transformer
- Branch circuit, run [illegible]cealed under flo[illegible] above
- Branch circuit, run exposed
- Branch circuit, run concealed under floor
- The character marked on tap circuits indicates two No. 14 conductors in ½-in. conduit
- This character marked on tap circuits indicates three No. 14 conductors in ½-in conduit
- This character marked on tap circuits indicates four No. 14 conductors in ¾-in. conduit unless marked ½ in.

This character marked on tap circuits indicates five No. 14 conductors in ¾-in. conduit

This character marked on tap circuits indicates six No. 14 conductors in 1-in. conduit unless marked ¾ in.

This character marked on tap circuits indicates seven No. 14 conductors in 1-in. conduit

This character marked on tap circuits indicates eight No. 14 conductors in 1-in. conduit

NOTE.—If larger conductors than No. 14 are used, use the same symbols and mark the conductor and conduit size on the run.

Feeder run concealed under floor above

Feeder run exposed

Feeder run concealed under floor

Pole line

Push buttom

Buzzer

Bell

Annunciator

Interior telephone

Public telephone

Clock, secondary

Clock, master

Time stamp

Electric door opener

Local fire-alarm gong

City fire-alarm station

Local fire-alarm station

Fire alarm-central station

Speaking tube

Nurse's signal plug

Maid's plug

Horn outlet

District-messenger call

Watchman station

Watchman central-station detector

Public telephone—P B X switchboard

Interconnection-telephone central switchboard

Interconnection cabinet

Telephone cabinet

Telegraph cabinet

Special outlet for signal system
As described in specifications

Battery

Signal wires in conduit concealed under floor

Signal wires in conduit concealed under floor above

35. Wiring of Concrete Buildings.—The rigid conduit system of wiring is the only one to be recommended for fireproof buildings. For such structures, either one of two methods of installing the conduits may be followed; that is, the conduits may be run either exposed or concealed. The method to be followed in any given case will be determined by local conditions although it may be said that the concealed system is to be preferred if the conditions will permit its installation.

35*a*. Exposed Conduit System.—In many concrete buildings it is not always practical to locate definitely the outlets during the process of construction. This is especially true of buildings intended for manufacturing purposes. Moreover, the installation of conduits in such a building after its completion is a laborious and expensive process unless some provision for such installation is made while the building is under construction.

The best plan to follow will be to a great extent determined by local conditions. Nevertheless, two quite common methods are the following; Fig. 31 shows a section of a reinforced concrete floor. Openings for the conduit are made by placing short pieces of pipe of proper diameter in the girder form. These pieces of pipe must be large enough to permit the easy insertion of the conduit, and they must also be of such length that when the forms into which the concrete is poured, are removed, the ends of the sleeves will be flush with the sides of the girders In most cases, 1¼ in. pipe will be large enough. The sleeves pass horizontally through

the girder near the ceiling line in every bay, or as near as possible to the neutral axis of the girder. They may be placed in all four sides of the bay so that several circuits can be run in. The sleeves must be in alignment, and they must be firmly fastened to the forms so that the pouring of the concrete and other operations, will not displace them. Then by using condulets and exposed iron panel boxes, a neat job of exposed conduit wiring is assured.

If the girders are steel I-beams, another plan must be followed. A convenient method of fastening the conduit in such instances is shown in Fig. 32. A board is first fastened under the girder by means of clips extending around the flange of the I-beam and screwed to the board. The conduit is then attached to the under side of the board by straps.

35b. Concealed Conduit Construction.—The exact plan to be followed in this type of construction will depend somewhat upon the form or style of concrete construction, but

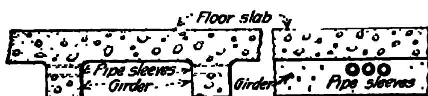


Fig. 31.

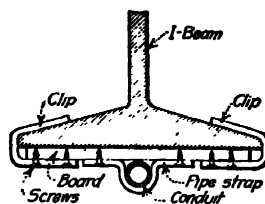


Fig. 32.



Fig. 33.

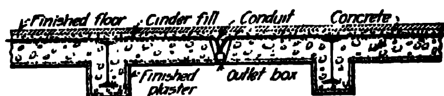


Fig. 34.

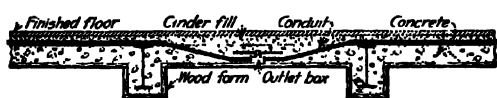


Fig. 35.

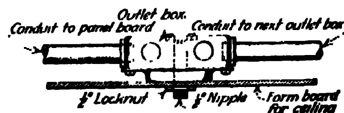


Fig. 36.

in general either one of two methods may be employed. In one system the conduits are installed after the concrete is all poured, set, and the forms removed. In the other system, the conduits and outlet boxes are fastened in place and the concrete is poured over them. If the conduits are to be installed after the removal of the forms, some provisions must be made for outlets through the concrete slabs before the concrete is poured, as structural engineers as a rule will not permit the cutting away of the reinforcing steel. One method of securing an opening through the concrete slab is to fit wooden blocks as is shown in Fig. 33. These blocks are specially made, and tapered as shown. The smaller end of each block is placed at the bottom, and its diameter is approximately that of an outlet box. In length, the blocks are equal to the thickness of the concrete slab. These blocks must be set and securely fastened before the concrete is poured. One good method of fastening them in place is by means of bolts as indicated. A hole is bored the whole length of the block and through the form. A bolt of proper length is inserted and a nut is screwed on from below.

Instead of blocks, tin tubes or sleeves, like those generally placed around steam pipes where they pass through the ceilings, may be used. These tubes should not be smaller than 3 in. in diameter, and about 6 in. long. Such tubes are fastened by flaring them out at the bottom and nailing them to the forms where outlets are required. To protect the tubes from being filled with concrete, they are filled with sand as soon as put in place.

When the concrete has set, and the forms have been removed, the conduit is installed as shown in Fig. 34. The conduit is bent and inserted into the outlet box which is placed flush

with the opening. This necessitates sharp bends, and the length of conduit extending into the opening must be short to prevent the box from being exposed.

Undoubtedly the best practice, however, is to fasten the outlet box to the forms before the concrete is poured. The wood forms are set with the reinforcing steel in place, and upon this the conduit is placed as shown in Fig. 35. Several methods may be employed for fastening the boxes in place. One method is to first fasten the conduit and fixture hanger to the box; then drive a nail at the exact center of the outlet and place the center of hanger over the nail at the outlet location. The box may then be fastened to the forms by wire nails which are driven part way into the boards and then bent over the box, or the nails may be driven through the screw holes in the bottom of the box. These nails must be cut out before the wire is drawn in.

To avoid sharp ends of nails in the boxes after forms are removed, either of the following plans is to be preferred: Drive on a slant four nails about half way into the forms on the opposite sides of the box. Then take a No. 14 soft-iron wire and make a turn or two around the head of each nail, crossing over the box from nail to nail. When this has been done, drive the nails down until the box is held firmly in place.

Another convenient method is shown in Fig. 36. A scrap piece of ½-in. conduit is tapped with a ⅜-in. tap and then screwed on to the fixture stud in the bottom of the box. A hole of the proper size is bored through the form and a piece of pipe is pushed into it. By means of a lock nut, the box is drawn up tight against the form and firmly held in place. When the concrete is set, the stem is unscrewed from the fixture stud, permitting the easy removal of the forms. The outlet boxes must be deep enough to permit the insertion of the conduit from the sides. These boxes are installed before the reinforcing steel is put in place, and the conduits are run immediately after the placing of the wire netting upon which they rest. In such a construction, the conduit serves as a reinforcement and can be completed back to the center of distribution. It may also be turned up or down at switch outlets as the case demands.

The ends of the conduits must be securely closed against the entrance of water or concrete. Some contractors use wooden plugs or tape covered with a waterproof compound for this purpose, while one contractor recommends the use of the circular pieces that are knocked out of the outlet boxes. These he fastens in place by slipping a knockout disk of proper size into a bushing and then screwing the bushing on to the exposed end of the pipe. Such a joint can readily be made water tight, and the construction is cheap. Switch outlets are usually placed on either the walls or the partitions. This fact necessitates bringing the conduit through the forms in the line of the walls or of the partition. Great care must be exercised to locate these outlets accurately, for after the cement has set, it is too late to change them. For vertical runs between floors it is a good plan to provide channels.

SECTION 7

ELECTRIC LIGHTING AND ILLUMINATION

BY C. M. JANSKY

1. General.—When lamps are placed in a room, the purpose is not to have a source of light to look at, but to make objects in the room visible and in some instance to enhance their beauty.

Objects are seen by reflected light; that is, light from some source after falling on the object is reflected by it to the eye where it excites the sensation of vision. By means of this sensation we can get a perception of the shape, size, color, and other physical characteristics of the object.

There are two types or kinds of reflection—specular and diffuse. If the object upon which the light falls is polished, it is invisible, for nearly all of the incident light is reflected at the same angle and an image of the source is seen. Polished surfaces such as mirrors, produce specular reflection. Light falling on a visible object is not all reflected at the same angle nor is all of it that is incident at a given point reflected to the eye, but it is dispersed or scattered. Such a reflection is known as diffuse. Objects are made visible by diffuse reflection.

The effectiveness of a system of illumination is thus indicated by the distinctness with which the objects are seen and their colors and other features are depicted. If the light source is in the direct line of sight, vision will not be distinct, for the eye automatically adjusts itself to the most brilliant object and prevents the entrance of sufficient light from the less brilliant objects to make them clearly visible. This is also true if one side or portion of an object is brilliantly illuminated while the other side is in shadow.

It is a mistake to assume that brilliant lights give the most efficient illumination. Efficient illumination is secured by a proper and even distribution of light rather than by great intensity. The artistic aspect of lighting fixtures, however, should not be neglected.

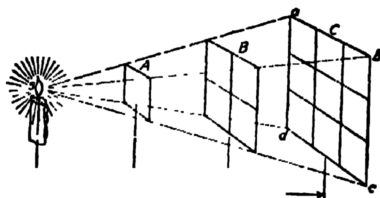


Fig. 1.

2. Light and Illumination.—Light is the physical condition of the ether which produces the sensation of vision. The sources of light are the sun, and other incandescent bodies. Those in which we are at present concerned are electric lamps. The high temperature of the lamp filament produces the condition in the ether which we call light. Illumination is the distribution of light on objects to make them visible. Light is the cause; illumination is the effect. The problem in designing a lighting system is to use light so as to obtain illumination without causing eye discomfort or strain. Lighting and illumination thus have utilitarian, artistic, and hygienic aspects. In a properly designed and efficient lighting and illumination system the sources of light should be of relatively low intrinsic brilliancy. They should be out of the direct range of vision and the distribution of light should be such that objects viewed are clear and distinct without excessive shadows or glare. Brilliancy of a lighting system is no guarantee of its efficiency from an illumination viewpoint. No modern light source should be exposed so as to be normally visible. Such a condition is harmful to the eye and contributes much toward making the lighting system unattractive.

In addition to the general factors mentioned above, many local or particular factors must be considered in designing a lighting system.

3. Distribution of Light.—If the source of light is a small incandescent ball, it is evident that it would appear equally bright from every direction. Such a body sends out light of equal intensity in every direction. The total amount of light emitted is commonly called the flux of light. Since light travels in straight lines, it is evident that a small area near the source of light will receive as much light as a larger one at a distance (Fig. 1). The small area will thus appear

more brillliantly illuminated. The illumination will also vary with the color and texture of the object and its inclination to the rays of light. Illumination is thus a function of many different factors among which the intensity or brillinacy of the light source is only one.

The brilliancy of a light source is a measure of the flux of light emitted. The intensity of light, or flux of light, in any specified direction is measured in *candles*. A *candle* is the luminous intensity of light emitted by a standard candle. This is a candle made according to certain definite specifications and burned under specified conditions. It is an arbitrary unit for measuring luminous intensity.

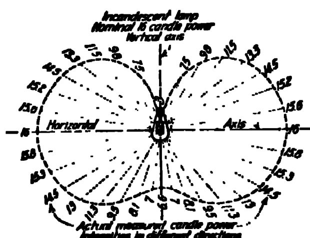


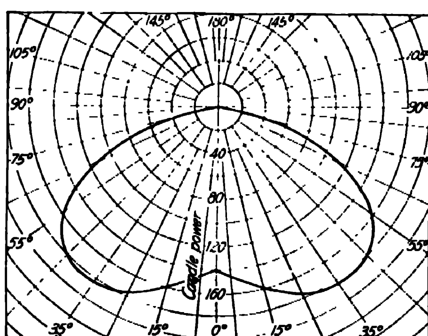
FIG. 2.

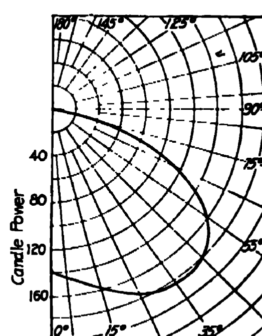
Since every practical artificial light source emits different quantities of light in different directions, the brilliancy in only one direction can be used as the unit of comparison. The light giving power in the horizontal direction has been made the basis of intensity measurements. By horizontal direction is meant every direction in a plane perpendicular to the axis of the light at its center.

The *candle power* of a lamp is its luminous intensity expressed in candles. The candle power of a lamp is usually different in different directions, hence the average or mean of the intensities is usually given. The average or mean candle power may be the average of the intensities in a great many different directions. For example, the *mean lower hemispherical* candle power of a lamp is the average of the candle power values in all directions below the horizontal. The *mean spherical* candle power of a lamp is the average of its candle power in all directions. The usual lu rating of lamps is expressed in mean horizontal candle power; that is, the average of all values of lumi tensity in the horizontal plane.

4. Distribution Curves.[1]—As pointed out, the luminous intensity or candle power of a lamp varies with the direction. Candle power in any direction is determined by comparison with the luminous intensity of a standard lamp. A typical or rather illustrative curve showing the variation in candle power of a 16-candle power carbon lamp is shown in Fig. 2. The measured luminous intensities are either tabulated or plotted in the form of curves (see Fig. 3). At the

ANGLE	CANDLE-POWER	ZONE	LUMENS
0	1420		
5	1480	0-10	14
15	1610	0-20	60
25	1780	0-30	142
35	1830	0-40	257
45	1810	0-50	397
55	1650	0-60	545
65	1080	0-70	652
75	441	0-80	699
85	51	0-90	704
90			





left the data are given in tabular form; at the center and right, the relations are shown by curves plotted to polar coördinates. The candle power at any angle is the average obtained as the lamp rotates about its vertical axis.

Distribution curves are graphical methods of presenting the data in the table. A distribution curve shows at a glance the variations in luminous intensities in different directions and the curves are thus simply convenient methods of presenting tabulated data. The area of a distribution curve is not a criterion of the total amount of light emitted by a lamp. Fig. 4 shows two distribution curves of two light sources emitting equal amounts of light flux.

In calculating the light flux in different zones it is customary to determine the average candle power for zones of 10 deg. width. It is sufficiently accurate for most purposes to assume that the candle power at the center of

[1] Bul. Eng. Dept., National Lamp Works of Gen. Elec. Co., No. 7G.

the zone represents the average candle power of the zone. The total light flux in lumens is then obtained by multiplying the candle power by the area of the zone on the surface of a sphere of 1 ft. radius. The factors by which such candle power values should be multiplied to give the lumens in each 10-deg. zone are:

Zone, degrees	Multiplying factors
0 to 10	0.0954
10 to 20	0.283
20 to 30	0.463
30 to 40	0.628
40 to 50	0.774
50 to 60	0.897
60 to 70	0.992
70 to 80	1.058
80 to 90	1.091

Above 90 deg. the factors are the same but in the reverse order.

5. Units of Illumination.—It is evident from Fig. 1, that the quantity of light from a point source falling on a given surface decreases as the square of the distance of the surface from source of light increases. The quantity of light that is incident upon a square foot at a distance of 1 ft. from the source is spread out over 4 sq. ft. at a distance of 2 ft.

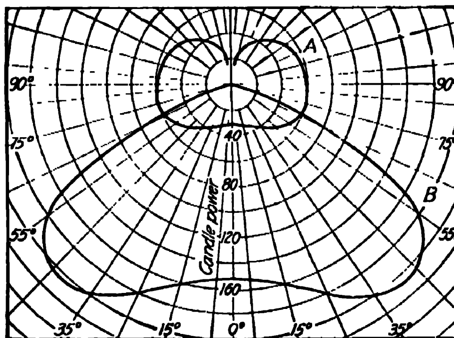


Fig. 4.

Evidently the illumination produced will vary with the quantity of light falling on the surface. That is, the illumination also varies inversely as the square of the distance of the illuminated surface from the light source.

A standard candle will produce a certain definite illumination on a surface at a distance of 1 ft. This illumination is called the *foot-candle*. It is a unit of illumination and not of candle power. In Fig. 1, if S is a lamp of 1 c.p. intensity, and A is a surface 1 ft. away, the illumination is 1 foot-candle. If the surface is farther away, like B for example, the illumination is less, or ¼ of a foot-candle. The foot-candle is a unit of illumination and accordingly any value expressed in foot-candles must be a value at one point only, unless it is given as an average value.

In calculating the illumination for a particular installation, it is convenient to select a horizontal plane on which it is assumed that illumination is desired. This plane, known as the *plane of illumination*, is usually 2 ft. 6 in. above the floor. In laying out a lighting system, it is customary to select an average foot-candle intensity on the plane of illumination, this average depending on the brilliancy of illumination desired. The lighting system is then designed to give this average value. With an average intensity in foot-candles on the plane of illumination, the intensity may vary considerably from point to point on the plane; but by using the right reflector at the proper height and by proper spacing of the lamps, the variation in intensity may be made negligible and the resulting illumination will be *uniform*.

The quantity of light emitted by a light source has been called the flux of light. The

amount of light that produces an average illumination of 1 foot-candle on an area of 1 sq. ft. is called a *lumen*. What is meant by a quantity of light will be better understood by reference to Fig. 1. The solid angle included by the planes *aSb*, *bSc*, *CSd*, and *ASd*, may be considered as including a certain amount of light. The luminous intensity in candle power may be different in different directions within the solid angle, but the quantity of light within the angle is a definite fixed amount. If this amount is such that the illumination on *A* per square foot is 1 foot-candle, the light flux in lumens is equal to the area of *A* in square feet. If *A* has an area of 1 sq. ft. and the average illumination is 1 foot-candle, the quantity or flux of light is 1 lumen. If we assume *S* to be a point source emitting light uniformly in all directions, then the total flux in lumens is equal to 4π times candle power of *S*.

Illustrative Problem.—According to curve in Fig. 3, the average candle power at an angle of 25 deg. from the vertical is 178. This is the middle of the 20 and 30-deg. zone. What is the light flux in this zone?

The multiplying factor for the zone 20 to 30 deg. is 0.463. The product of 0.463 × 178 = 82.4 lumens. The table to the left gives 142 − 60 = 82 lumens.

To use these factors with any light unit take the candle power from a light distribution curve at the middle of the zone and multiply this candle power by the zone factor. Thus, to obtain the light flux in the 0 to 10-deg. zone, read the candle power intensity at 5 deg. and multiply by the 0 to 10-deg. zone factor, etc. Distribution curves are now used principally for determining the proper reflector for use in given locations to secure the proper light distribution.

6. Essentials of Good Illumination.[1]—The essential characteristics of a satisfactory illumination system or installation are: (*a*) efficiency, (*b*) uniformity, (*c*) diffusion, (*d*) eye protection, (*e*) color value, and (*f*) appearance.

6*a*. Efficiency.—By efficiency is meant the useful percentage of the total quantity of light emitted by the light source. By useful light is meant the light which actually produces illumination on the surface or object desired. It is light that remains after subtracting the light absorbed by the reflecting equipment and the ceiling and walls. Efficiency as used here is sometimes termed "utilization efficiency." It is expressed as a percentage of the total number of lumens incident on the working plane and this percentage is called "utilization factor." A knowledge of utilization factors is necessary for the design of an efficient lighting system. Table[2] 1 gives utilization factors upon the working plane for a number of typical conditions.

While efficiency should be considered in the design of a lighting system, it is not always of prime importance especially in comparison with eye protection. It should not be sacrificed, however, unless there is a corresponding gain in some other factor. On large installations, it will always pay to calculate the cost of any sacrifice which is made in efficiency in order to be sure that it is justified.

6*b*. Uniformity.—By uniform illumination is meant the freedom from variation in the light distribution in a room or space. When the same foot-candle intensity is obtained at every point on the working plane, the illumination is uniform. Although absolute uniformity is not necessary in practice, streaks of excessive brightness and shadows are to be avoided because they are tiring to the eyes.

Degree of uniformity is usually expressed as a percentage deviation from the mean or average. Thus, if the average illumination is 2 foot-candles, the maximum 2.4 foot-candles, and the minimum 1.5 foot-candles, the greatest deviation from the average is 0.5 foot-candles. This is 25% of the average. Therefore, the degree of uniformity is expressed as 25% maximum deviation from the mean.

Illumination that does not have a greater deviation than 30% from the mean is, for all practical purposes, uniform illumination. The eye cannot detect such a variation in an ordinary room. Variations considerably greater than this are often found even in well laid out systems. In rooms where close work is to be performed, such as offices, drafting rooms, schools and the like, 30% maximum deviation is a desirable limit. In stores, churches, theatres, many parts of factories, etc., variations up to 50% may be allowed. In such places as warehouses, stock rooms, corridors, etc., still greater variations in illumination are not serious.

[1] The Lighting Handbook, Gen. Elec. Co.

[2] Fundamentals of Illumination Design, National Lamp Works of Gen. Elec. Co.

Table 1.—Coefficients of Utilization

This table applies to installations in *square rooms* having sufficient lighting units symmetrically arranged to produce reasonably uniform illumination. To obtain the coefficient for any rectangular room, find the value for a square room of the narrow dimension and add one-third of the difference between this value and the coefficient for a square room of the long dimension.

	Reflection factor: Ceiling			Light, 70 %			Medium, 50 %		Dark, 30 %
	Reflection factor: Walls			Light, 50 %	Medium, 35 %	Dark, 20 %	Medium, 35 %	Dark, 20 %	Dark, 20 %
	Reflector type	Light output	Ratio = room width / ceiling height						
1			1	0.42	0.38	0.35	0.36	0.34	0.33
			1½	0.50	0.46	0.43	0.44	0.42	0.41
			2	0.56	0.52	0.49	0.50	0.47	0.45
			3	0.63	0.59	0.55	0.56	0.53	0.51
			5	0.70	0.66	0.63	0.63	0.60	0.57
2			1	0.31	0.27	0.24	0.24	0.21	0.18
			1½	0.37	0.33	0.30	0.30	0.27	0.24
			2	0.43	0.39	0.35	0.34	0.31	0.27
			3	0.49	0.45	0.41	0.39	0.36	0.31
			5	0.56	0.52	0.48	0.45	0.42	0.36
3			1	0.44	0.37	0.34	0.35	0.33	0.32
			1½	0.49	0.45	0.42	0.43	0.41	0.39
			2	0.54	0.50	0.47	0.48	0.46	0.44
			3	0.60	0.56	0.53	0.53	0.51	0.49
			5	0.67	0.63	0.59	0.59	0.57	0.54
4			1	0.38	0.36	0.34	0.35	0.33	0.33
			1½	0.45	0.43	0.41	0.42	0.40	0.40
			2	0.49	0.47	0.45	0.46	0.44	0.44
			3	0.54	0.52	0.50	0.51	0.49	0.49
			5	0.59	0.57	0.55	0.56	0.54	0.54
5			1	0.43	0.40	0.38	0.39	0.37	0.37
			1½	0.52	0.49	0.47	0.48	0.46	0.46
			2	0.57	0.54	0.52	0.53	0.51	0.51
			3	0.63	0.60	0.58	0.59	0.57	0.57
			5	0.69	0.66	0.64	0.65	0.63	0.63
6			1	0.22	0.19	0.17	0.14	0.12	0.07
			1½	0.27	0.24	0.22	0.17	0.15	0.09
			2	0.31	0.28	0.26	0.20	0.18	0.11
			3	0.36	0.33	0.31	0.24	0.22	0.13
			5	0.42	0.39	0.37	0.28	0.26	0.16
7			1	0.27	0.24	0.21	0.20	0.17	0.14
			1½	0.34	0.30	0.27	0.25	0.22	0.18
			2	0.39	0.35	0.32	0.29	0.26	0.21
			3	0.45	0.41	0.38	0.34	0.31	0.25
			5	0.51	0.47	0.44	0.40	0.37	0.29
8			1	0.24	0.21	0.19	0.16	0.14	0.10
			1½	0.30	0.27	0.24	0.20	0.18	0.13
			2	0.34	0.31	0.28	0.23	0.21	0.15
			3	0.39	0.36	0.33	0.27	0.25	0.18
			5	0.45	0.42	0.39	0.32	0.30	0.21
9			1	0.23	0.20	0.17	0.18	0.16	0.14
			1½	0.30	0.26	0.23	0.21	0.21	0.19
			2	0.35	0.31	0.28	0.28	0.25	0.22
			3	0.41	0.37	0.34	0.33	0.30	0.26
			5	0.48	0.44	0.41	0.39	0.36	0.31
10			1	0.32	0.28	0.26	0.27	0.25	0.23
			1½	0.40	0.36	0.33	0.34	0.32	0.30
			2	0.45	0.41	0.38	0.39	0.37	0.35
			3	0.52	0.47	0.44	0.45	0.42	0.40
			5	0.59	0.54	0.51	0.51	0.48	0.46

Uniform illumination can be obtained by the proper placing of lamps and by the use of properly designed reflectors. This is shown in Fig. 5 To secure uniform illumination on the working plane with different types of reflectors, the lamps must be mounted at different heights. Not only is the mounting height of the lamp dependent upon the type of reflector, but also upon the spacing of the lamps. A table of maximum spacings and minimum mounting heights is given in Table 2.

TABLE 2.—RECOMMENDED MAXIMUM SPACINGS AND MINIMUM MOUNTING HEIGHTS FOR VARIOUS UNITS

(Mounting height equals distance of light source above plane of illumination)

Equipment	* Ratio = Spacing / Mounting height	† Ratio = Mounting height / Spacing
Prismatic, mirror, or aluminum:		
Intensive	1½	⅔
Focusing	¾	1⅓
Extensive	1⅔	⅗
Indirect or semi-indirect	1½ ‡	⅔ ‡
Opal or porcelain enamel:		
Bowl	1⅔	⅗
Dome	1⅔	⅗
Totally enclosing glass	1⅔	⅗
Semi-enclosing	1½	⅔

* To get maximum spacing distance, multiply Ratio by height

† To get minimum mounting height, multiply Ratio by

‡ Height equals distance between ceiling and plane of ill

6c. Diffusion.—Diffusion of illumination may be defined as the degree to which the light received at any point comes from different directions. If the light received at any point on the plane of illumination comes from many directions, the diffusion is good; if it comes from only a few directions, the diffusion is poor. An example of good diffusion is furnished by indirect lighting in which the light on the plane of illumination comes from a large area—the ceiling. An example of poor diffusion is illumination obtained from a single opaque parabolic reflector which projects the light in a single direction. A high degree of diffusion eliminates shadows and glare. Poor diffusion of illumination is characterized by excessive brightness at some portions of the field of view resulting in impaired vision and discomfort to the eye.

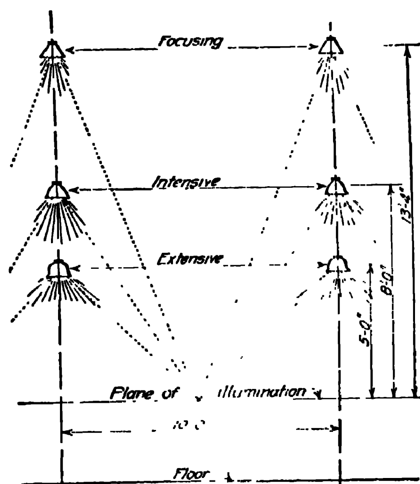


FIG. 5.

Another type of glare, contrast glare, is due to excessively bright light sources in comparison with other objects. Authorities state that to avoid this type of glare, visible light sources should not be more than 200 times as bright as their background, and preferably not over 100 times, in ordinary artificial lighting of interiors where the average illumination on the working plane is from 3 to 6 foot-candles, and for higher illu nation intensities than 6 foot- this limit of contrast should be less than 100 to 1.

6d. Eye Protection.—The importance of protecting the eyes against the injurious effects of improperly placed lights, excessive brightness, glare, and other harmful consequences of an improperly designed lighting system cannot be too strongly emphasized. Many public and assembly halls are very poorly lighted in this respect. Lights are placed on the stage or are suspended from the ceiling over the stage in such a position that they shine directly into the eyes of persons in the audience. Such practice is inexcusable. Eye protection should be given first consideration in any illumination scheme. In any well-designed lighting system, care should be taken so to place and shade light sources that the bare, brilliant source will not be in the range of vision and there will not be extreme contrasts of light and shade. When reflectors are used they should be deep enough to conceal the lamp from view at all ordinary angles of vision. The glare from a brilliant light source is most detrimental where the light source is close to the line of sight. As it is moved away from the line of sight, the glare decreases and practically ceases when the angle between the line of sight and the line from the lamp to the eye is over 25 deg. The maximum angle of glare effect is shown in Fig. 6. Three

clear globe lamps in the sockets would be quite objectionable. A deep panel reflector will remove this objection and prevent harmful glare. Under all ordinary conditions, deep bowl reflectors, covering the lamp down to 65 deg., give sufficient shielding for good eye protection. It is evident that a glass reflector to be effective must not transmit too much light. The reflectors should be of prismatic construction or the glass should be of sufficient opacity to greatly reduce the amount of transmitted light. Ground glass or opalescent glass should not be used especially with gas-filled (Type C) Mazda lamps.

6e. Color Value.—The eye has developed under the stimulus of the light of the sun or white light as it is commonly called. The color of an illuminated body may be due to several causes. It is obvious that the color of an object will depend fundamentally upon that of the illuminating light; but since we are so accustomed to viewing objects by sunlight, in describing the color of an object the illumination is always assumed to be white light. White light or sunlight is then the normal light for ordinary illumination purposes. When artificial light sources are used, the light should approach white light as closely as possible. In churches, residences, theatres, and many classes of stores and factories, white light is not essential and the usual types of reflecting equipment are entirely satisfactory. On the other hand, white light is quite essential in establishments such as drygoods and clothing stores, millinery shops, art galleries, furniture stores, florists shops, color-printing shops, hospitals, doctor's offices, etc., or any place where color is an important factor in determining the value or condition of the object. In laying out a lighting system it is usually unnecessary to give much consideration to the color question, except to avoid colors that are disagreeable and injurious to the eyes. In many cases, as pointed out above, the shades, reflectors, and lamps should be carefully considered in order that as near as possible white light may be secured.

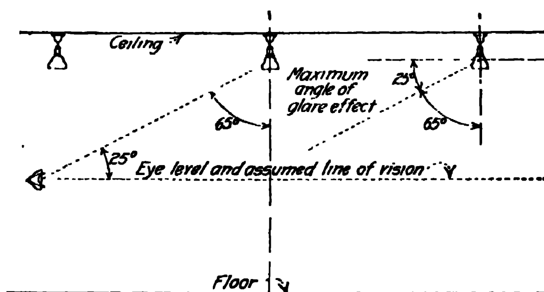


FIG. 6.

6f. Appearance. The purpose of illuminating objects is not merely to show their presence and to facilitate movement, but also to arouse emotions; that is, to create pleasurable and informative impressions on the human mind. In other words, the function of lighting is not narrowly utilitarian but it also has an esthetic value. "Since it is the pattern made by rays of varying intensity and of varying color on the retina, calling up various reminiscences to our mind, that enables us to see, to understand what lies before us, it follows that the type of lighting that sets in motion the most powerful train of associative ideas is the one that may have greatest emotional effect; but the intensity of the emotional effect is not proportional to the intensity of the light even though the intensity of that light may affect the clearness with which the different physical aspects of the object are discerned. The physical aspects are not always the most interesting features; we are often more interested in the memories called up by the object."[1] Proper lighting is, therefore, of tremendous artistic importance, and the illumination engineer and the architect should jointly plan the lighting system so that the result may not be garish but artistic and harmonious.

7. The Design of Lighting Systems.—In designing a lighting system the following process is usually followed: (1) the selection of the type of lighting system and lighting units, (2) calculation of the quantity and distribution of the light flux, and (3) determination of the location and size of lighting units.

8. Types of Lighting Systems.—In general, the different lighting systems may be classed as direct, indirect, and semi-indirect. Although no definitions of these terms have been agreed upon, nevertheless, certain distinctions and characteristics are usually recognized as explained in the following articles.

[1] Lowell, Illuminating Engineering Practice.

Direct lighting **is a term applied to a system of lighting in which the light is projected either directly or by means of a reflector mounted on the lamps in the direction of the objects to be illuminated. Any lamp enclosed in a ball globe or equipped with a glass ornamental reflector, arranged to reflect the light toward the object illuminated, is classified as direct lighting (Fig. 7). The energy efficiency, measured in watts per foot-candle on illuminated surface, is highest in direct lighting.**

An *indirect lighting system* is one in which all the light is first reflected to the ceiling or walls from which it is again reflected to the plane to be illuminated. Before reaching the plane of illumination the light undergoes at least two and perhaps more reflections (Fig. 8). Since some light is absorbed at each reflection, it is evident that the energy efficiency is comparatively low.

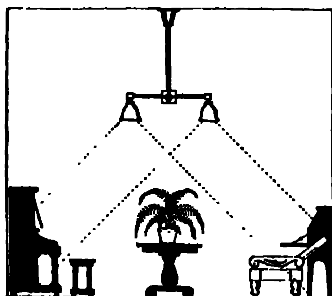


Fig.

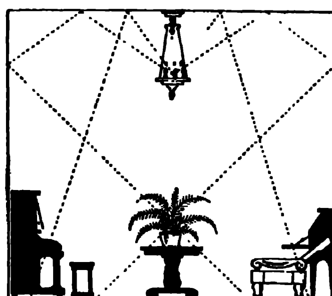
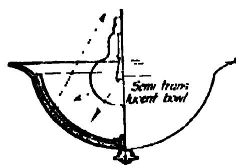


Fig. 8.

A *semi-indirect lighting system* is a combination of the direct and indirect lighting systems. In this system a part of the light is projected or reflected directly upon the plane of illumination, but the greater part is directed to the ceilings or walls from which it is reflected to the proper plane. This is illustrated in Fig. 9. The diffusing bowls for semi-indirect lighting should be of such density that when illuminated they are no brighter than the ceiling. The energy efficiency of semi-indirect lighting is less than that of direct lighting. Indirect or semi-indirect lighting is nearly always the best for offices, schoolrooms, and many other types of work rooms.

9. Local and General Illumination.—Illumination may also be considered with reference to space lighted. We thus have *local* and *general* illumination. In local illumination, attention is given only to the objects or space to be illuminated without reference to the surroundings—as, for example, where a lamp is used over a desk. In general illumination the light is distributed over the surrounding objects as well as over a given particular space. Local lighting should not be used by itself but only in combination with general illumination.



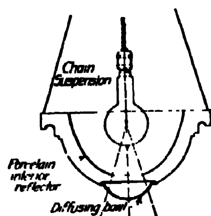


Fig. 9.

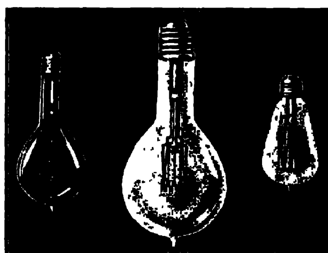
10. Selection of Lighting Units.[1]—Whether gas or electric lamps shall be used will depend on local conditions. Both the electric incandescent lamp and the gas mantle burners are adapted to the illumination of almost any kind of interior from the roughest to the most refined. For the illumination of certain types of offices and industrial plants, the mercury vapor lamp is also available. The color of the light from the mercury vapor lamp is objectionable from an artistic standpoint although it has not been found harmful. It is especially well adapted for drafting rooms and the like.

In choosing between the electric incandescent lamp and the gas mantle burner, the following factors will guide in the proper selection: (*a*) relative cost per 1000 lumens at current prices; (*b*) relative convenience of control; (*c*) blacking of walls and ceiling by gas; (*d*) variation in pressure of gas and of voltage in electric supply; (*e*) the relative cost of glassware and mantle renewals; (*f*) no lighting unit should be chosen which does not permit the use of proper globe, shade, or reflector to secure the satisfactory distribution of light and does not satisfy hygienic requirements.

[1]Principles of Interior Illumination by Cravath, Harrison and Pierce, Illuminating Engineering Practice, pp. 64 and 65.

Masda lamps on the market are of two types, B and C (Fig. 10). The type B lamp differs from the type C lamp in that the bulb contains no gas and the filament of tungsten is not concentrated. The lamp is operated at lower brilliancy and hence is somewhat less efficient. The type C lamp also contains a tungsten filament, but this is usually in spiral or other concentrated form and the bulb contains some inert gas, such as nitrogen. The two types are more accurately designated as vacuum and gas-filled tungsten lamps. The term Masda is a trade name.

The vacuum tungsten lamps are supplied in either straight side or round bulbs for voltages of 110 to 125 and 220 to 250 volts, Table 3. The light efficiency ranges from 7.5 lumens per watt for the 10- watt amp. to 10.6 lumens per watt for the 100-watt round bulb lamp.



The tungsten filaments of the gas filled lamps are mounted in pear shaped bulbs of clear and blue-green colored glass. The trade designation of the former is type C and of the latter, type C-2. The efficiencies of the type C lamps range from 11.5 lumens per watt for the 75-watt 110 to 125-volt lamp to approximately 18 lumens per watt for the 1000-watt lamp of the same voltage and class. The type C-2 lamps employ blue-green colored glass for the bulbs and are designed for general illumination when approximately daylight color quality is desired. The total light output of the lamps is somewhat decreased by the absorption of the colored bulb. The luminous efficiencies are of the same order as those of the vacuum lamps. Recently there has been placed on the market a gas-filled lamp in an opalescent bulb, Fig. 11.

The filaments of all gas-filled lamps are intensely bright and hence should always be screened from the eye.



Fig. 11.

11. Quantity and Distribution of Light.—The range of possible illumination intensities for illumination varies from a fraction of a foot-candle to several thousand foot-candles. If the intensities are too low, however, it is impossible to distinguish detail, and thus there is a minimum intensity below which illumination is not satisfactory. There is not exact limit to the upper ranges but considerations of economy usually limit the intensities to the lower values for artificial illumination. Another consideration that determines the illumination intensity is the use and character of the room or space to be illuminated. It cannot therefore be said that certain illumination intensities will give the most satisfactory illumination under all conditions, but under the limitations mentioned above, they will give satisfactory results. Illumination intensities that will fulfill these requirements for various classes of service are given in Table 4.

TABLE 3.—ILLUMINATION AND OTHER DATA ON ELECTRIC LAMPS[1]

Watts	Volts	Bulb	Mazda B or Mazda C lamp	Lighting service	Rated initial lumens	Rated initial lumens per watt	Mean lumens per cent of average initial lumens	Mean l.p.w per cent of rated initial	Hours life	Amperes	Screw base	Maximum over-all length, inches	Light center length, inches	Position of burning
10	115	S-14 cl	B	Sign	72	7.2	..	..	1,500	.....	Medium	3 1/2	2 1/2	Any
10	115	S-14 col.	B	Spec.	....	...	..	..	1,500	.....	Medium	3 1/2	...	Any
15	28–32	A-17	C	C.H.	149	9.9	..	..	1,000	.....	Medium	3 5/8	2 3/8	Any
15	32	A-17	C	Train	149	9.9	90	92	1,000	.....	Medium	3 5/8	2 3/8	Any
15	33	S-14 cl.	B	L.C	135	9.0	..	..	1,000	.....	Medium	3 1/2	2 1/2	Any
15	64	A-17	B	Train	134	8.9	..	..	1,000	.....	Medium	3 5/8	2 3/8	Any
15	115	A-17	B	Dec.	126	8.4	90	93	1,000	.....	Medium	3 5/8	2 3/8	Any
15	115	S-14 blue	B	Sign	75	....	..	..	1,500	.....	Medium	3 1/2	2 1/2	Any
15	115	G-18 1/2 fr.	B	Gen'l.	120	8.0	85	88	750	.....	Medium	3 9/16	.....	Any
15	115	F-10 F.T.	B	Dec.	...	....	..	..	600	.....	Cand.	3 1/4	1 5/8	Any
15	115	F-10 fr.	B	Dec.	115	....	..	..	600	.....	Cand.	3 1/4	1 5/8	Any
23	115	S-17 cl.	B	St. Ry.	216	8.8	89	92	1,500	0.214	Medium	4 5/8	.....	Any
23	115	A-19 cl. H.	B	S.R.H.	194	7.9	..	..	1,000	0.214	Medium	3 15/16	2 3/16	Any
23	115	G-18 1/2 cl. H.	B	S.R H.	194	7.9	..	..	1,000	0.214	Medium	3 9/16	2 3/16	Any
25	28–32	A-19	C	C.H.	290	11.6	..	..	1,000	.....	Medium	3 15/16	2 1/2	Any
25	32	A-19	C	Train	290	11.6	93	94	1,000	.....	Medium	3 15/16	2 1/2	Any
25	64	A-19	C	Train	247	9.9	..	..	1,000	.....	Medium	3 15/16	2 1/2	Any
25	115	A-19	B	Gen'l.	235	9.4	87	91	1,000	.....	Medium	3 15/16	2 1/2	Any
25	115	A-19 col.	B	Spec.	...	....	..	..	1,000	.....	Medium	3 15/16	...	Any
25	115	A-19 F.T.	B	Spec.	....	....	..	..	1,000	.....	Medium	3 15/16	.....	Any
25	115	A-19 cl. bl.	B	Sign	153	....	..	..	1,000	.....	Medium	3 15/16	2 1/2	Any
25	115	G-18 1/2 fr.	B	Gen'l.	230	9.2	82	85	750	.....	Medium	3 9/16	.....	Any
25	115	G-18 1/2 F.T.	B	Gen'l.	...	....	..	..	750	.....	Medium	3 9/16	....	Any
25	115	G-25 fr.	B	Gen'l	230	....	..	..	750	.....	Medium	4 7/16	....	Any
25	115	G-25 F.T.	B	Gen'l.	.....	....	..	..	750	.....	Medium	4 7/16	....	Any
25	115	F-15 F.T.	B	Dec	...	....	..	..	750	.....	Medium	4 1/2	....	Any
25	115	F-15 fr.	B	Dec.	223	....	..	..	750	.....	Medium	4 1/2	....	Any
25	115	T-10 cl.	B	Lim.	225	9.0	..	..	1,000	.....	Medium	5 5/8	....	Any
25	230	A-19	B	H.V.	202	8.1	89	91	1,000	.....	Medium	3 15/16	2 1/2	Any
36	115	S-19 cl.	B	St. Ry	374	9.5	85	90	1,500	0.342	Medium	5 3/16	....	Any
36	115	A-19 cl H.	B	S R.H.	335	8.5	..	..	1,000	0.342	Medium	3 15/16	2 3/16	Any
36	115	G-18 1/2 cl. H.	B	S.R H.	335	8.5	..	..	1,000	0.342	Medium	3 9/16	2 3/16	Any
40	115	A-21	B	Gen'l.	396	9.9	84	88	1,000	.....	Medium	4 7/16	2 7/8	Any
40	115	A-21 F.T.	B	Spec.	...	....	..	..	1,000	.....	Medium	4 7/16	....	Any
40	115	G-25 fr.	B	Gen'l.	390	....	..	..	750	.....	Medium	4 7/16	....	Any
40	115	G-25 F.T.	B	Gen'l	...	....	..	..	750	.....	Medium	4 7/16	....	Any
40	115	T-8 cl.	B	Lim.	380	9.5	..	..	1,000	.....	Medium	11 7/8	...	Any
50	28–32	A-21	C	C H.	720	14.4	..	..	1,000	.....	Medium	4 15/16	3 3/8	Any
50	32	A-21	C	Train	720	14.4	93	94	1,000	.....	Medium	4 15/16	3 3/8	Any

50	64	A-21	C	Train	605	12.1			1,000	.....	Medium	4 15/16	3 3/8	Any
50	115	A-21	C	Gen'l.	515	10.3	93	94	1,000	.....	Medium	4 15/16	3 3/8	Any
50	115	A-19	B	R.S.	435	8.7	..	.	1,000	.....	Medium	3 15/16	2 1/2	Any
50	115	A-21 F.T.	C	Spec		....		..	1,000		Medium	4 15/16	....	Any
50	115	A-19 cl. bl.	B	Sign	325				1,000	...	Medium	3 15/16	2 1/2	Any
50	230	A-21	B	H.V.	460	9.2	85	88	1,000		Medium	4 7/16	2 7/8	Any
50	275	A-21	B	Mine	425	8.5			1,000		Medium	4 7/16	2 7/8	Any
50	300	A-21	B	Mine	425	8.5			1,000		Medium	4 7/16	2 7/8	Any
56	115	S-21 cl.	B	St. Ry.	591	9.9			1,500	0.519	Medium	5 1/4	....	Any
56	115	P-25 cl. H.	B	S.R.H	519	8.7			1,000	0.519	Medium	4 3/4	2 11/16	Any
60	115	A-21	C	Gen'l	666	11.1	93	94	1,000		Medium	5 1/4	3 3/4	Any
60	115	A-21 day	C	Gen'l	441		..	.	1,000		Medium	5 1/4	3 3/4	Any
75	115	PS-22 cl.	C	Gen'l	930	12.4	91	92	1,000		Medium	5 7/8	4 3/8	Any
94	115	S-24½ cl.	B	St. Ry	1,062	10.7			1,500	0.863	Medium	6 15/16	....	Any
94	115	P-25 cl. H	B	S.R.H	864	8.7			1,000	0.863	Medium	4 3/4	2 11/16	Any
100	28–32	A-23	C	C.H	1,620	16.2			1,000		Medium	6 1/16	4 3/8	Any
100	32	A-23	C	Train	1,620	16.2	93	94	1,000		Medium	6 1/16	4 3/8	Any
100	32	P-25 cl.	C	L.H	1,450	14.5			500		Medium	4 3/4	3	Base down
100	64	A-23	C	Train	1,460	14.6			1,000		Medium	6 1/16	4 3/8	Any
100	115	A-23	C	Gen'l	1,320	13.2	91	92	1,000		Medium	6 1/16	4 3/8	Any
100	115	A-23 day	C	Gen'l	878	....			1,000		Medium	6 1/16	4 3/8	Any
100	115	P-25 cl	C	Spot	1,270	12.7			200		Medium	4 3/4	3	Base down
100	115	PS-25 wh.	C	Gen'l	1,190	11.9	80	82	1,000		Medium	6 15/16		Any
100	230	A-23	C	H.V	1,040	10.4	93	94	1,000		Medium	6 1/16	4 3/8	Any
150	115	PS-25 cl	C	Gen'l	2,310	15.4	90	91	1,000		Medium	6 15/16	5 1/4	Any
150	115	PS-25 W.B.	C	Gen'l.					1,000		Medium	6 15/16	5 1/4	Any
150	115	PS-25 day	C	Gen'l	1,500				1,000		Medium	6 15/16	5 1/4	Any
200	115	PS-30 cl	C	Gen'l	3,240	16.2	90	91	1,000		Medium	8 1/8	6	Any
200	115	PS-30 W.B.	C	Gen'l		...			1,000		Medium	8 1/8	6	Any
200	115	PS-30 day	C	Gen'l	2,106				1,000		Medium	8 1/8	6	Any
200	230	PS-30 cl.	C	H.V	2,680	13.4		..	1,000		Medium	8 1/8	6	Any
200	230	PS-30 W.B.	C	H.V		..			1,000		Medium	8 1/8	6	Any
250	32	P-25 cl.	C	L.H	4,400	17.6			500		Medium	4 3/4	3	Base down
250	115	G-30 cl.	C	Spot	4,175	16.7			200		Medium	5 1/8	3	Base down
250	115	G-30 cl.	C	Flood	3,425	13.7			800		Medium	5 1/8	3	Base down
250	115	T-14 cl.	C	Proj	5,750	23.0	..	..	50		Medium	5 1/2	3	Base down
300	28–32	T-16 cl.	C	Proj	7,200	24.0			50		Medium	5 1/2	3	Base down
300	115	PS-35 cl.	C	Gen'l	5,280	17.6	90	91	1,000	..	Mog.	9 5/16	7	Any
300	115	PS-35 W.B.	C	Gen'l.	....	....	..	..	1,000	.....	Mog.	9 5/16	7	Any
300	115	PS-35 day	C	Gen'l.	3,430	....	..	.	1,000	...	Mog.	9 5/16	7	Any
300	230	PS-35 cl	C	H.V.	4,290	14.3	..	.	1,000	.	Mog.	9 5/16	7	Any
300	230	PS-35 W.B.	C	H.V	...	..	..	.	1,000	.	Mog.	9 5/16	7	Any
400	115	G-30 cl.	C	Spot.	7,440	18.6	..	.	200	...	Medium	5 1/8	3	Base down
500	115	G-40 cl.	C	Flood.	8,200	16.4	..	..	800	..	Mog.	7 1/16	4 1/4	Base down
500	115	T-20 cl.	C	Proj.	12,300	24.6	..	..	50	....	Medium	5 1/2	3	Base down

TABLE 3.—ILLUMINATION AND OTHER DATA ON ELECTRIC LAMPS[1]—*Continued*

Watts	Volts	Bulb	Mazda B or Mazda C lamp	Lighting service	Rated initial lumens	Rated initial lumens per watt	Mean lumens per cent of average initial lumens	Mean l.p.w. per cent of rated initial	Hours life	Amperes	Screw base	Maximum over-all length, inches	Light center length, inches	Position of burning
500	115	PS-40 cl	C	Gen'l.	9,500	19.0	88	89	1,000	.....	Mog.	9 13/16	7	Any
500	115	PS-40 W.B.	C	Gen'l.	...	. .	.	..	1,000	...	Mog.	9 13/16	7	Any
500	115	PS-40 day	C	Gen'l.	6,180	. .	..	..	1,000	..	Mog.	9 13/16	7	Any
500	230	PS-40 cl.	C	H.V.	8,050	16.1	..	..	1,000	. .	Mog.	9 13/16	7	Any
500	230	PS-40 W.B.	C	H.V.	......	. .			1,000	.	Mog	9 13/16	7	Any
750	115	PS-52 cl	C	Gen'l	14,775	19.7	84	85	1,000		Mog.	13 1/8	9 1/2	Any
750	115	PS-52 W.B.	C	Gen'l.		.	..		1,000	.	Mog.	13 1/8	9 1/2	Any
750	230	PS-52 cl.	C	H.V.	12,900	17.2		.	1,000	....	Mog.	13 1/8	9 1/2	Base up
750	230	PS-52 W.B.	C	H.V.	....	...	.	..	1,000	...	Mog.	13 1/8	9 1/2	Base up
1,000	115	PS-52 cl	C	Gen'l.	21,000	21.0	81	82	1,000	.	Mog.	13 1/8	9 1/2	Any
1,000	115	PS-52 W.B.	C	Gen'l			.	.	1,000	. .	Mog.	13 1/8	9 1/2	Any
1,000	115	T-20 cl.	C	Proj	26,800	26.8	...	.	50	..	Mog.	9 1/16	4 3/4	Base down
1,000	230	PS-52 cl.	C	H.V.	18,200	18.2	..	.	1,000	..	Mog.	13 1/8	9 1/2	Base up
1,000	230	PS-52 W.B.	C	H.V.	. .	..	.	..	1,000	....	Mog.	13 1/8	9 1/2	Base up

[1] NOTE.—Data furnished by Engineering Department of National Lamp Works of General Electric Company. Corrected to April, 1927.

Abbreviations

Aver	Average
Bl	Blue
Cand	Candelabra
C.H.	Country home
Cl.	Clear
Col	Colored red, blue, green, yellow, or amber-orange
Day	Daylight
Dec.	Decorative
Fil. Const	Filament construction
Flood	Floodlighting
Fr.	Frosted
F.T.	Flametint
Gen'l.	General
H.	Headlight
Hrs.	Hours
H.V.	High voltage
L.C	Locomotive cab
L.H	Locomotive headlight
Lim	Limited
L.P.W	Lumens per watt
Ltg. Serv	Lighting service
Lums.	Lumens
Med	Medium
Mog.	Mogul
Mog. Sk	Mogul skirted
Proj.	Projection

R.S.	Rough Service
Spec.	Special
Spot.	Spotlight
S.R.H.	Street railway headlight
St. Ry	Street railway
St. Sr	Street series
W.B.	White Bowl
Wh	White
115	110, 115 and 120

TABLE 4.—RECOMMENDED ILLUMINATION INTENSITIES FOR DIFFERENT CLASSES OF SERVICE[1]

1 Class of service	2[2] Method of illumination	3[3] Suitable kind of lighting	4[4] Intensity of illumination, foot-candles
Armory	G	D	2.0- 3.0
Assembly room	G	D, SI, I	0.5- 1.5
Auditorium	G	D, SI, I	1.0- 3.0
Automobile show room	G	D, SI	3.0- 6.0
Ballroom	G	D, SI	2.0- 5.0
Bank, general	G	I, SI, D	2.0- 3.0
Bank, desk	G, L	D, SI,	4.0- 6.0
Barber shop	G, L	D, SI, I	3.0- 5.0
Billiard room:			
General	G	D, SI	0.8- 1.5
Tables	L	D	6.0-10.0
Bowling alley	G, L	D	1.0- 2.0
Bowling pins	G, L	D	4.0- 6.0
Cafe, general only	G	I, SI, D	2.0- 4.0
Cafe, with table lights	G, L	SI	1.0- 2.0
Card room	G	D	2.0- 3.0
Church	G	I, SI, D	2.0- 3.0
Corridors	G	D, SI	0.5- 1.5
Court room	G	D, SI	2.0- 4.0
Desk	L	D	4.0- 6.0
Drafting room	G, L	I, SI, D	6.0-12.0
Garage	G, L	D	2.0- 3.0
Gymnasium	G	D	2.0- 4.0
Hospital:			
Ward room, dim	G	I, SI	0.2- 0.3
Ward room, bright	G	I, SI	2.0- 3.0
Operating table	L, G	D	15.0-25.0
Hotel:			
Bedroom	G, L	SI, D	1.5- 3.0
Dining room	G	SI, D	2.0- 4.0
Dining room	G, L	SI	1.0- 2.0
Lobby	G	SI, D	2.0- 4.0
Library:			
Stack room	L, G	D	1.5- 2.0
Reading room	G	SI	3.0- 4.0
Reading room	G, L	SI, D	1.0- 1.5
Office:			
Large	G	SI, D	3.5- 5.0
Large	G, L	SI, D	1.5- 2.0
Small (private)	G, L	SI, D	3.0- 4.0
Small, general	G	SI	3.0- 5.0
Residence:			
Hall	G	SI, D	0.7- 1.0
Parlor	G	SI, D	1.0- 3.0
Living room	G	SI, D	1.5- 2.5
Dining room	G	SI, D	1.0- 3.0
Library	G, L	SI, D	1.5- 2.5
Kitchen	G, L	D	2.0- 3.0
Laundry	G	D	1.5- 3.0
Bathroom	G, L	D	2.0- 3.0
Bedroom	G, L	SI, D	1.0- 3.0
Store and furnace rooms	G	D	0.4- 0.8
Schools:			
Auditorium	G	SI, D	2.0- 4.0
Blackboards	G	SI, D	3.0- 5.0
Class rooms	G	SI, D	3.0- 5.0
Laboratories	G	SI, D	3.0- 5.0
Sewing rooms	G, L	SI, D	5.0-10.0
Shop rooms	G, L	D	2.0- 6.0

TABLE 4.—*Continued*

1 Class of service	2[2] Method of illumination	3[3] Suitable kind of lighting	4[4] Intensity of illumination, foot-candles
Stores:			
Large department stores:			
Main floors	G	SI, I, D	6.0-10.0
Other floors	G	SI, I, D	4.0-7.0
Stores of medium size:			
Book and stationery	G	SI, D	3.0-6.0
Clothing	G	SI, D	4.0-7.0
Drug	G	SI, D	4.0-6.0
Dry goods	G	SI, D	4.0-7.0
Furniture	G	SI, D	3.0-5.0
Grocery	G	SI, D	3.0-5.0
Exclusive small stores:			
Light goods	G	SI, I, D	6.0-10.0
Dark goods	G	SI, I, D	8.0-12.0
Small stores in general.			
Art	G	SI, D	5.0-8.0
Book	G	D, SI	3.0-5.0
Bakery	G	D, SI	3.0-4.0
Butcher	G	D, SI	3.0-4.0
Cigar	G	D, SI	4.0-6.0
Clothing	G	D, SI	4.0-7.0
Confectionery	G	D, SI	3.0-5.0
Decorator	G	D, SI	4.0-5.0
Drug	G	D, SI	3.0-6.0
Dry goods	G	D, SI	4.0-7.0
Florist	G	D, SI	3.0-4.0
Furrier	G	D, SI	5.0-7.0
Grocery	G	D, SI	3.0-4.0
Haberdashery	G	D, SI	5.0-7.0
Hardware	G	D, SI	3.0-4.0
Hat	G	D, SI	4.0-6.0
Jewelry	G	D, SI	4.0-6.0
Millinery	G	D, SI	4.0-6.0
Notions	G	D, SI	3.0-5.0
Shoe	G	D, SI	3.0-4.0
Tailor	G	D, SI	4.0-7.0
Theatre:			
Auditorium	G	SI, D	1.0-3.0
Moving picture, dim	G	SI, D	0.1-0.3
Moving picture, bright	G	SI, D	1.0-2.0
Station:			
Waiting room	G	D	2.0-3.0

[1] Holophane Works of Gen. Elec. Co., Engineering Dept., National Lamp Works of Gen. Elec. Co., F. A. Vaughn and others.

[2] In column 2, G means general and L means local illumination.

[3] In column 3, D means direct, SI semi-indirect and I, indirect lighting.

[4] In column 4, the intensities of illumination are those recommended by various authorities. The illumination intensities for general illumination are the average over the working plane. The values given for general and local illumination are those recommended for general lighting.

12. Determination of Size and Location of Lamps.—When the type of lighting and the intensity of illumination has been decided upon, the next step is the determination of the exact size and location of the lighting units. The problems under this head are in general of two types: *viz.*, either local illumination of a certain intensity will be required while little consideration will be given to general illumination, or minimum and maximum intensities for general illumination are specified and little regard is given to local lighting.

In the problems of the first class, it is assumed that a certain number of foot-candles illumination is desired at a particular point. Such problems are solved by what is known as the "point-by-point" method of illumination calculation. The general principles of the method are as follows: In Fig. 12, let

Cp = candle power of lamp in the direction from lamp to T.
h = height in feet of lamp above the plane of illumination.
l = distance in feet of point T from lamp.
I_h = illumination intensity in foot-candles on horizontal plane at T.
I_v = illumination intensity in foot-candles on a vertical plane.

Then the illumination in foot-candles at point T on plane TB is

$$\text{Illumination} = \frac{Cp}{l^2} \text{ foot-candles}$$

Since the plant TB makes an angle with the plane of illumination, the intensity of illumination on plane AT at point T is

$$I_h = \frac{Cp}{l^2} \cos \phi \text{ foot-candles}$$

The candle power of the lamp in the direction of T is taken from the photometric or candle power distribution curve. As this is usually plotted for 5-deg. values of ϕ, and as h is fixed, it is more convenient to express the illumination intensity on the horizontal plane at T in terms of Cp, h, and $\cos \phi$. Thus,

$$l^2 = \frac{h^2}{\cos^2 \phi}$$

$$I_h = \frac{Cp}{\frac{h^2}{\cos^2 \phi}} \cos \phi$$

$$= \frac{Cp}{h^2} \cos^3 \phi$$

In exactly the same way the illumination intensity on a vertical plane can be calculated from the equation

$$I_v = \frac{Cp}{s^2} \sin^3 \phi$$

where s is the horizontal distance from the point T to the vertical dropped from the lamp, or TA (see Fig. 12).

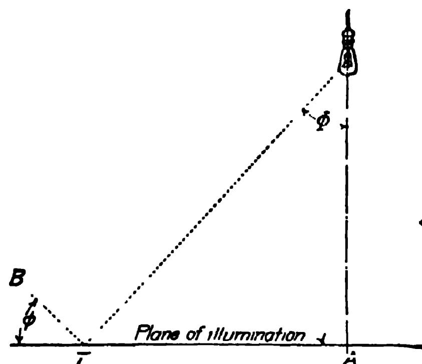


Fig. 12.

The candle powers to be substituted in the above formulas are taken from the distribution curves in the particular direction. They are not the nominal rated candle power of the light source. To facilitate calculation, values of $\cos^3 \phi$ for degree intervals are given in Table 5. The process explained above may, however, be reversed and the size of lamp required to give a certain assumed illumination intensity for local illumination be calculated. Thus, if I is given, we have

$$Cp = \frac{Ih^2}{\cos^3 \phi}$$

That is, the candle power in the desired direction is obtained by multiplying the illumination intensity on the horizontal plane by $\frac{h^2}{\cos^3 \phi}$. If the position of the illumination plane is not specified, the result will be approximately correct if the illumination intensity in foot-candles is multiplied by the square of the distance, in feet, of the point to be illuminated from the lamp. By comparing the candle power thus calculated with the candle power curves of lamps

TABLE 5.—TABLE OF $\cos^3$ AND $\sin^3$

$\phi°$	$\sin\phi$	$\sin^3\phi$	$\cos\phi$	$\cos^3\phi$	$\phi°$	$\sin\phi$	$\sin^3\phi$	$\cos\phi$	$\cos^3\phi$
0	0.0000	0.0000	1.000	1.000	43	0.682	0.317	0.731	0.301
1	0.0175	0.0000	1.000	1.000	44	0.695	0.335	0.719	0.372
2	0.0349	0.0000	0.999	0.998	45	0.707	0.354	0.707	0.354
3	0.0523	0.0001	1.999	0.996	46	0.719	0.372	0.695	0.335
4	0.0698	0.0003	0.998	0.993	47	0.731	0.391	0.682	0.317
5	**0.0872**	**0.0007**	**0.996**	**0.989**	**48**	**0.743**	**0.410**	**0.669**	**0.300**
6	0.105	0.0011	0.995	0.984	49	0.755	0.430	0.656	0.282
7	0.122	0.0018	0.993	0.978	50	0.766	0.450	0.643	0.266
8	0.139	0.0027	0.990	0.971	51	0.777	0.469	0.629	0.249
9	0.156	0.0038	0.988	0.961	52	0.788	0.489	0.616	0.233
10	**0.174**	**0.0052**	**0.985**	**0.955**	**53**	**0.799**	**0.509**	**0.602**	**0.218**
11	0.191	0.0069	0.982	0.946	54	0.809	0.530	0.588	0.203
12	0.208	0.0090	0.978	0.936	55	0.819	0.550	0.574	0.189
13	0.225	0.0114	0.974	0.925	56	0.829	0.570	0.559	0.175
14	0.242	0.0142	0.970	0.913	57	0.839	0.590	0.545	0.162
15	**0.259**	**0.0173**	**0.966**	**0.901**	**58**	**0.848**	**0.610**	**0.530**	**0.149**
16	0.276	0.0209	0.961	0.888	59	0.857	0.630	0.515	0.137
17	0.292	0.0250	0.956	0.875	60	0.866	0.650	0.500	0.125
18	0.309	0.0295	0.951	0.860	61	0.875	0.669	0.485	0.114
19	0.326	0.0345	0.946	0.845	62	0.883	0.688	0.470	0.103
20	**0.342**	**0.0400**	**0.940**	**0.830**	**63**	**0.891**	**0.707**	**0.454**	**0.9036**
21	0.358	0.0460	0.934	0.814	64	0.899	0.726	0.438	0.0842
22	0.375	0.0526	0.927	0.797	65	0.906	0.744	0.423	0.0755
23	0.391	0.0596	0.921	0.780	66	0.914	0.762	0.407	0.0673
24	0.407	0.0673	0.914	0.762	67	0.921	0.780	0.391	0.0597
25	**0.423**	**0.0755**	**0.906**	**0.744**	**68**	**0.927**	**0.797**	**0.375**	**0.0526**
26	0.438	0.0843	0.899	0.726	69	0.934	0.814	0.358	0.0460
27	0.454	0.0936	0.891	0.707	70	0.940	0.830	0.342	0.0400
28	0.470	0.104	0.883	0.688	71	0.946	0.845	0.326	0.0345
29	0.485	0.114	0.875	0.669	72	0.951	0.860	0.309	0.0205
30	**0.500**	**0.125**	**0.866**	**0.650**	**73**	**0.956**	**0.875**	**0.292**	**0.0250**
31	0.515	0.137	0.857	0.630	74	0.961	0.888	0.276	0.0209
32	0.530	0.149	0.848	0.610	75	0.966	0.901	0.259	0.0173
33	0.545	0.162	0.839	0.590	76	0.970	0.914	0.242	0.0142
34	0.559	0.175	0.829	0.570	77	0.974	0.925	0.225	0.0114
35	**0.574**	**0.189**	**0.819**	**0.550**	**78**	**0.978**	**0.936**	**0.208**	**0.00899**
36	0.588	0.203	0.809	0.530	79	0.982	0.946	0.191	0.00695
37	0.602	0.218	0.799	0.509	80	0.985	0.955	0.174	0.00524
38	0.616	0.233	0.788	0.489	81	0.988	0.664	0.156	0.00383
39	0.629	0.249	0.777	0.469	82	0.990	0.971	0.139	0.00270
40	**0.643**	**0.266**	**0.766**	**0.450**	**83**	**0.993**	**0.978**	**0.122**	**0.00181**
41	0.656	0.282	0.755	0.430	84	0.995	0.984	0.105	0.00114
42	0.669	0.300	0.743	0.410	85	0.996	0.989	0.0872	0.0006

TABLE 6.—PERCENT INCREASE IN ILLUMINATION

Color of ceiling	Color of walls	Increase over calculated illumination
Very dark	Very dark	0 per cent
Medium	Very dark	15 per cent
Medium	Medium	40 per cent
Very light	Very dark	30 per cent
Very light	Medium	35 per cent
Very light	Very light	80 per cent

of different sizes, the proper lamp can be selected. If photometric curves for all sizes of lamps are not available, the proper size can usually be calculated with sufficiently close approximation from curves of one size of lamp.

It is evident that the illumination calculated by above formulas does not consider the influence of the light reflected from walls and surrounding objects. The increase in illumination produced by this reflected light is impossible to determine in advance, as it depends upon the size of the room, type of reflectors, color, and condition of the walls and ceiling. The approximate percent increases are indicated in Table 6.

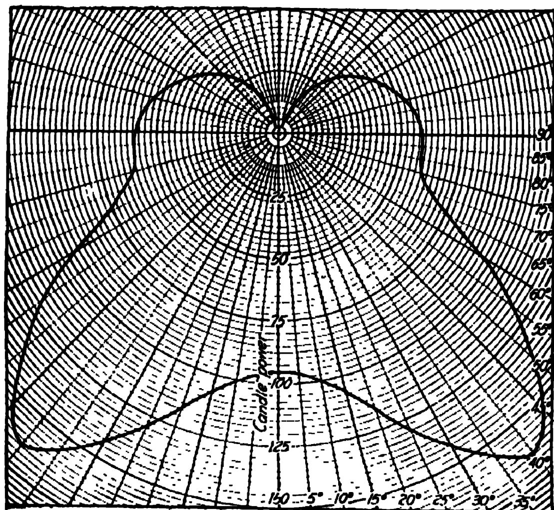


Fig. 13.

Illustrative Problem.—The photometric curve (Fig. 13) is for the type of light source that has been selected for a given installation. The lamp is a 100-watt vacuum tungsten lamp What size lamp must be used to give an illumination of 4 foot-candles at a distance of 8 ft. from the light source and at an angle of 25 deg. with the vertical through the lamp? The color of the ceiling is very light and the walls medium.

Table 6 shows that the increase in illumination for very light ceilings and medium walls is about 35 %. Hence, the direct illumination will be about 3 foot-candles and that due to reflection, 1 foot-candle. The candle power of the lamp in the direction desired is then

$$Cp = (3)(8)^2 = 192$$

Curve (Fig. 13) shows the 100-watt lamp emits 129 candle power at an angle of 25 deg. with the vertical, hence, the lamp required is

$$\frac{(100)(192)}{129} = 149 \text{ or } 150 \text{ watts.}$$

Most of the illumination problems are, however, of the second type, viz., those requiring a certain average general illumination. These problems are most readily solved by the flux-of-light method of illumination calculation. The process consists in first determining the illumination desired on the working plane, and also assuming the spacing of the lamps such as to give a reasonable degree of uniformity. The next step is the calculation of the total light flux in lumens required to be generated by the lamps. This is obtained by the simple formula Lumens =

$$\frac{\text{Area (sq. ft.)} \times \text{intensity (ft.-candles)}}{\text{coefficient of utilization}}$$

$$L = \frac{AI}{k}$$

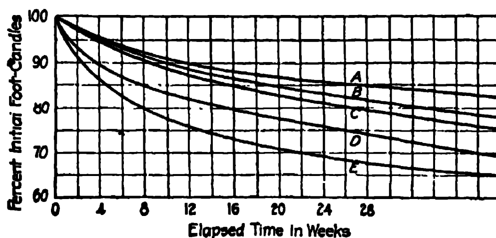


Fig. 14.

where A is the area of the working plane, I is the desired illumination intensity, and k is the coefficient of utilization as given in Table 1. In applying the foregoing formula the important thing is to select the proper value of k, due allowance being made for dirt and age of lamp. The depreciation caused by dust is shown by curves in Fig. 14. If opaque reflectors are used, k can be determined for most large interiors from the distribution curve of the lamp and reflector by dividing the total lumens emitted by the lamp by the lumens emitted in the zone from 0 to 70 deg. For smaller rooms, a smaller zone should be used.

When the total number of lumens required are determined, there remains the determination of the size of the lamps and their location. These two are interrelated quantities, for the number of outlets is determined by the architectural features of the room, such as the ceiling panels, and considerations of symmetry. The ideal condition is when the ceiling is divided into a number of squares with an outlet at the center of each square. Frequently such an arrangement is impossible; nevertheless, long and narrow rectangles should be avoided. Th size of squares that may be used with direct lighting is given in Table 7.[1]

TABLE 7.—DESIRABLE SIZES OF SQUARES—DIRECT LIGHTING

Kind of room	Ceiling height (feet)	Desirable length of side of square (feet)
Armories, auditoriums, churches, public halls, restaurants, etc.	12-16	12-16
	Over 16	15-26
Stores	8-11	8-11
	11-15	10-16
	Over 15	14-22
Offices, libraries, school rooms, drafting rooms, etc.:		
With additional desk lamps	10-20	12 18
Without additional desk lamps	9 12	7 11
	12 16	9-14
	Over 16	11-18

NOTE.—It is desirable not to use the largest size square with the smallest ceiling height given

The most satisfactory spacing of outlets for indirect and semi-indirect lighting depends largely upon the ceiling height. The distance between outlets should not be greater than approximately 1⅔ times the height of the ceiling above the working plane. The exact distance in any case will be determined by local conditions. In drafting rooms and offices where close work is performed, the spacing should be less. Fig. 15[1] shows the best spacings that are required together with the best drop from the ceiling. Fig. 16[1] shows the widest spacings permissible.

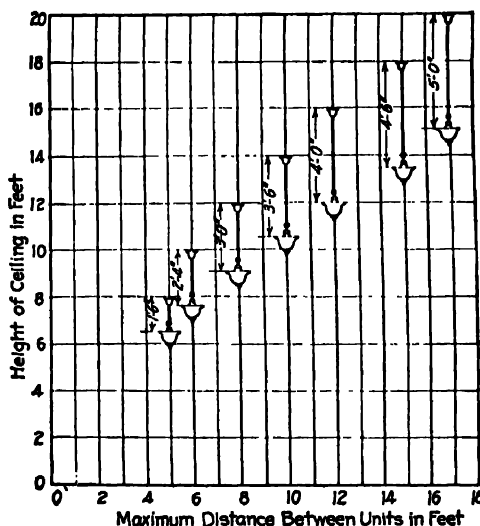


FIG. 15.

Illustrative Problem.—It is desired to design a lighting system for a large office room, 50 × 100 ft. and 15 ft. high. The ceilings are white or very light, and the walls greenish gray, medium.

Assuming no local lighting, the system should be designed to avoid glare, hence, due to the size of the room an indirect system is selected. By Table 4, the illumination intensity for large offices ranges from 4 to 8 foot-candles. Assume 6 foot-candles.

$$\text{Ratio of room width to ceiling heigth} = \frac{50}{20} = 2.5, \text{ use } 3$$

Then by Table 1 for mirrored glass reflector and for medium walls, the coefficient of utilization is 0.33

$$\text{Total lumens} = \frac{(50)\ (100)\ (6)}{0.33} = 91{,}000 \text{ nearly}$$

Allowing 25 % for the dimming effect of dust and depreciation of lamps, the total lumens necessary is 120,000

[1] General Electric Handbook.

According to chart Fig. 15, the spacing for a 20-ft. ceiling is 17 ft. If architectural features permit, the lamps may be located as indicated in Fig. 17. If columns or other features interfere, adjustments must be made. This will necessitate 18 outlets. The lumens per outlet are

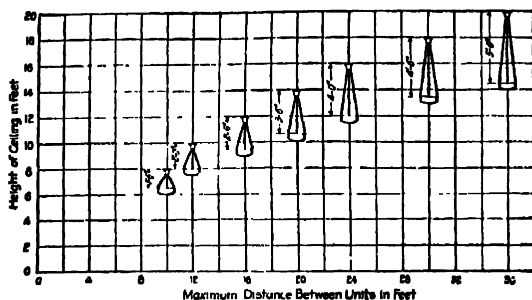


Fig. 16.

$$\text{Lumens per outlet} = \frac{120{,}000}{18} = 6679$$

Reference to Table 3 shows that a 400-watt Mazda type C lamp generates 6150 lumens and a 500-watt lamp of same type generates 8050 lumens. If the reflectors and ceilings are kept clean, the 400-watt lamp may be used. If the office is in a location where dust and soot rapidly accumulate, the 500-watt lamp should be used.

Illustrative Problem.—It may be of interest to note the influence of the height of the room. Suppose all conditions the same as in the preceding illustrative problem but the ceilings only 15 ft. high. How many outlets and what size of lamp will give satisfactory results?

Use indirect system as before. Use 6 foot-candles for illumination intensity.

$$\text{Ratio of room width to ceiling height} = \frac{50}{15} = 3\tfrac{1}{3}, \text{ use } 3$$

Reference to Table 1 for mirrored reflector shows the coefficient of utilization equal to 0.33 for a room 50 ft. square. Ratio of width to ceiling height for a room 100 ft. square is $\frac{100}{15} = 6\frac{2}{3}$, use 5. Coefficient of utilization for this ratio is 0.39. The coefficient of utilization for a room 50 × 100 ft. is then

$$0.33 + 1\tfrac{1}{3}(0.39 + 0.33) = 0.35$$

$$\text{Total lumens} = \frac{(50)(100)(6)}{0.35} = 86{,}000, \text{ nearly}$$

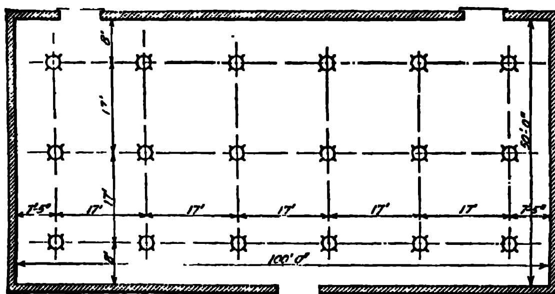


Fig. 17.

Assuming as before 25% for depreciation due to dust and falling off in lamp output, the total number of lumens necessary is 114,500.

The spacing according to Fig. 15 should be 11 ft. Considerations of symmetry necessitate a modification of this spacing. The outside rows of lamps may be placed 5.5 ft. from the walls, and the two end rows, 6 ft. from the walls. Across the room the lamps may be spaced 13 ft. and lengthwise, 11 ft. There will then be 4 rows, 9 outlets per row, or 36 outlets in all.

Since 114,500 lumens are required, lumens per outlet equals

$$\frac{114{,}500}{36} = 3180$$

Reference to Table 3 shows that 200-watt type C lamps give 2920 lumens, hence they would undoubtedly prove satisfactory.

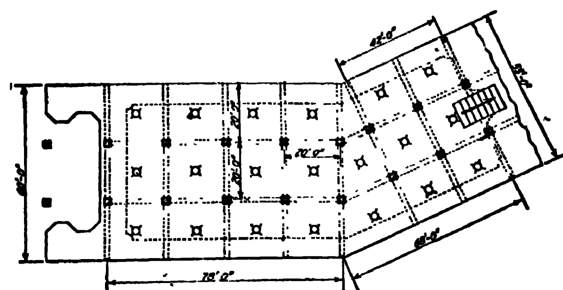


Fig. 18.—Electric illumination.

Illustrative Problem.—Assume a small drygoods store 25 × 50 ft., and 12 ft. high. Ceiling is white, walls dark. How many and what size lamps should be used?

Referring to Table 4, the illumination intensity is found to be 4 to 7 foot-candles. Assume 5 for moderate lighting and assume a semi-direct lighting system.

Ratio of width of room to ceiling height = $\frac{25}{12}$ = 2 for a 25-ft. square room and $\frac{50}{12}$ = 4 for a 100-ft. square room; use 5 in the latter case. The coefficient of utilization for a light opal reflector, light ceiling and dark walls is

$$0.32 + \tfrac{1}{3}(0.44 - 0.32) = 0.36$$

$$\text{Lumens required} = \frac{(25)(50)(5)}{0.36} = 17{,}400$$

Assuming a depreciation of 25 % the lamps will have to generate 23,250 lumens. Table 7 shows that a spacing of 12 ft. is approximately correct. This will necessitate two rows of 5 lamps each, or 10 lamps in all. The number of lumens per outlet is 23,250 ÷ 10 = 2325, and 150 type C Mazda lamps will undoubtedly prove satisfactory.

Illustrative Problem.—A large clothing store, Fig. 18,[1] is to be lighted. Calculate the number and size of lamps required. Dimensions: front part of store, width, 60 ft. and length, 78 ft. rear portion of the store, width, 55 ft., and average length, 55 ft. The color of the ceiling is a light cream and of the walls, dark.

Ratio of width to ceiling height $= \frac{60}{16} = 4$, nearly, for the front part and $\frac{55}{16} = 3+$ for the rear. Assume 3 as the average.

A direct lighting system of the type represented by 9, Table 1 was selected. The coefficient of utilization is

$$k = 0.34 + \tfrac{1}{3}(0.41 - 0.34) = 0.37$$

The total area of the store is $(60)(78) + (55)(55) = 7705$ sq. ft.

$$\text{Lumens} = \frac{(7705)\ (8)}{0.37} = 167{,}000$$

Assuming a depreciation of 16 %, the total lumens necessary is

$$\frac{167{,}000}{0.84} = 198{,}600$$



Fig. 19.

The floor plans show that the ceiling is divided into 21 bays which practically fix the location of the outlets. Lamps may be conveniently located in 20 of these bays, hence, the lumens per lamp are 198,600 ÷ 20 = 9930.

From the viewpoint of good vision, 500-watt type C lamps would furnish enough light. In this instance, brilliant illumination was the determining factor and 750-watt lamps were used. Fig. 19 shows the installation.

13. Lighting Accessories.[2]—By lighting accessories are meant the equipment, such as reflectors, shades, globes, and other devices for modifying and controlling the light emitted by lamps. The usual functions of such devices are to redirect the light; to diffuse the light; to intercept the light in certain directions; to modify the hue of the light; and to protect the light source. These functions will have different degrees of importance in different installations, hence it is evident that to fulfill all conditions of use, the number and variety of designs of lighting accessories is very great. Although there is no exact line of demarkation between the light controlling accessories, nevertheless, they may be considered under three separate headings: reflectors, shades, and globes.

[1] Bul., Fundamentals of Illumination Design, Eng. Dept. National Lamp Works of Gen. Elec. Co.

[2] Little, Illuminating Engineering Practice, p. 183.

13a. Reflectors.—All accessories reflect more or less light, but the term reflector is applied to that class of lighting accessories whose function it is to redirect the greater percentage of the light incident upon it. Reflectors may be made of metal, porcelain, or glass; with polished or mirrored surfaces, or of prismatic form. Reflectors may further be subdivided into two classes concentrating and distributing. Sometimes three classes are listed—focusing, intensive, and extensive. These names are self-explanatory as they have reference to the degree of light distribution by the reflector. Fig. 20 shows two forms of aluminum finished metal reflectors of the concentrating and distributing types.

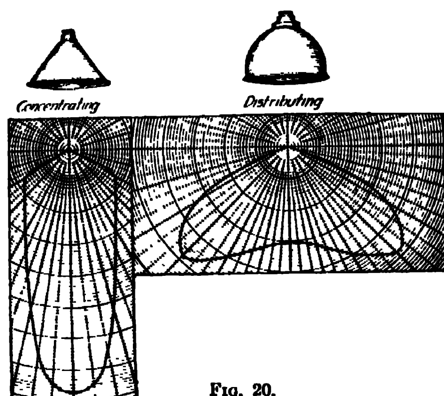


FIG. 20.

Porcelain enameled reflectors are made of steel, the refl ting surface being coated with porcelain enamel Th enamel coating should be dense so that as little light as possible penetrates to the steel, for all light that penetrates to the steel is absorbed. For industrial lighting, several manufacturers have placed on the market a porcelain enameled reflector designated as the R. L. M. Standard. The specifications of this type of reflector have been worked out jointly and this label is a guarantee that the reflector is up to the accepted standard in size, finish, screening angle, and finish of the reflecting surface.

Mirrored glass reflectors are made of clear glass blown in the proper shape, on the reflecting surface of which is spread a thin layer of silver This layer is then ·ted by a thin coating of enamel. To prevent the formation of brilliant images of the lamp filament or striat ›n the illuminated surface, the reflector surface is corrugated (Fig. 21).

Prismatic Reflectors.—If a ray of light in passing through glass is incident on the surface opposite to that at which it is entered at an angle greater than the critical angle for that kind of glass, it will be totally reflected. This is the principle of the prismatic reflector. The inner surface is usually smooth or lightly ground while the outer surface is formed into prisms. These prisms are made of such an angle that most of the incident light is reflected. Since it is mechanically impossible to construct a prismatic glass reflector so that all of the light emitted by the lamp will be incident at the proper angle for total reflection, some light passes through. This light is diffused and the bright filament of the lamp is well screened from the eye when viewed through the reflector. These reflectors together with their distribution curves are shown in Fig. 22.

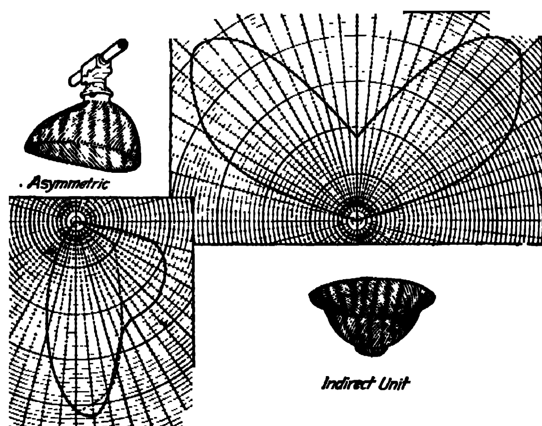


FIG. 21.

Reflectors are also made of opal glass. By the proper selection of thickness and densities, varied effects may be secured The dense opal accessory when properly shaped may produce an excellent reflector so far as light control is concerned. These accessories may be made thin and thus transmit considerable light, or thick and transmit comparatively little The diffusing properties are rather good especially where the surfaces are somewhat roughened. The characteristic candle power curves for bowl reflectors of opal glass are shown in Fig. 23.

13b. Globes and Shades.– Globes and shades are suitable only for shading and diffusing the light. They are made in a g·eat variety of forms and designs and are usually made of some kind of glass, opal, cased, roughed and etched crystal and alabaster.

14. Choice of Accessory.—The type and size of lamp used in any installation determines the type of reflector required because of the different efficiencies and distribution curves. The type of reflector to be used cannot be determined on the energy efficiency basis alone; other factors, such as ease of maintenance and absence of characteristics producing eye strain, must also be considered. A shallow bowl reflector should not be used with the long or mogul base lamps. In no case should the tip of the lamp project beyond the reflector.

Asymmetric Concentrating Distributing

Fig. 22.

15. Lighting of Offices.—The general principles of illumination design described in the preceding sections apply in office lighting but the relative importance of the several factors is not the same. The matter of first importance in office lighting are sufficient and uniform illumination, absence of glare, and efficient utilization of light. The artistic factors should be considered, but the hygienic factor should take precedence.

15a. Location and Number of Lighting Units.[1]—In many cases, the constructional features of the ceiling of the office will determine the number and location of lighting units. In the case of offices built to rent, the lamp outlets should be located in such a way that if the offices are remodeled to suit the requirements of a new tenant, they may still be usable. This consideration in many cases will necessitate a greater number of outlets than the existing lighting conditions require. Fig. 24 shows how an office with 6 lighting units may be divided into two offices and each be provided with adequate outlets. Sometimes it may be desirable to wire locations where it is thought units may at some future time be desirable, but to seal the wires beneath the plaster until required.

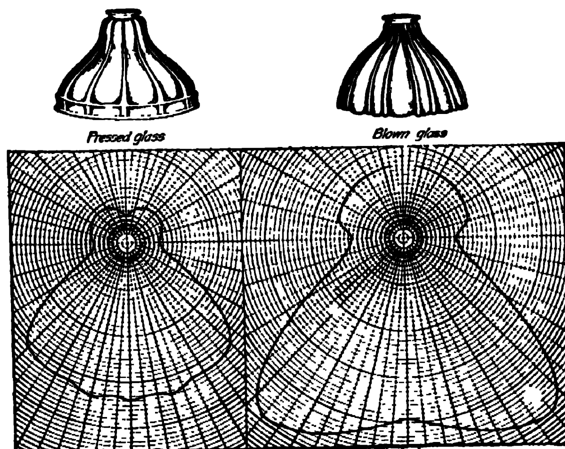


Fig. 23.

One of the most important considerations in office lighting is the elimination of glare. From a study of the light distribution of units, fairly definite rules have been formulated for the size of units and their spacing both with reference to each other and with reference to the walls. The application of such rules involves the width and length of the room to be lighted, the height of the ceiling, and the height at which the sources can be located above the working plane. In the case of indirect or semi-indirect lighting, the height of the light source above the working plane is the height of the ceiling above the desk and table tops. The distance between the lamp and

[1] Lighting of Offices and Drafting Rooms, Engineering Department National Lamp Works of General Electric Co.

ceiling in case of indirect and semi-indirect lighting is determined largely by considerations of appearance; nevertheless, there are certain limits which may be noted. The lamps should not be placed so near the ceilings that the corners appear objectionably dark, nor should the lamps be hung so low that light is directed to the walls. Between these limits variations in hanging height affect the efficiency of the installation very slightly. The recommended ratios of spacing to height of light source for satisfactory office illumination are given in Table 8. The significance of the several symbols is exemplified by the diagram below the table. The principles of Table 8, are perhaps more readily applied by the aid of diagrams, Fig. 25, whose application will be readily understood from the following illustrative problem.

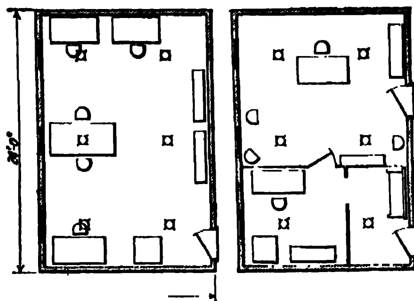


Fig. 24.

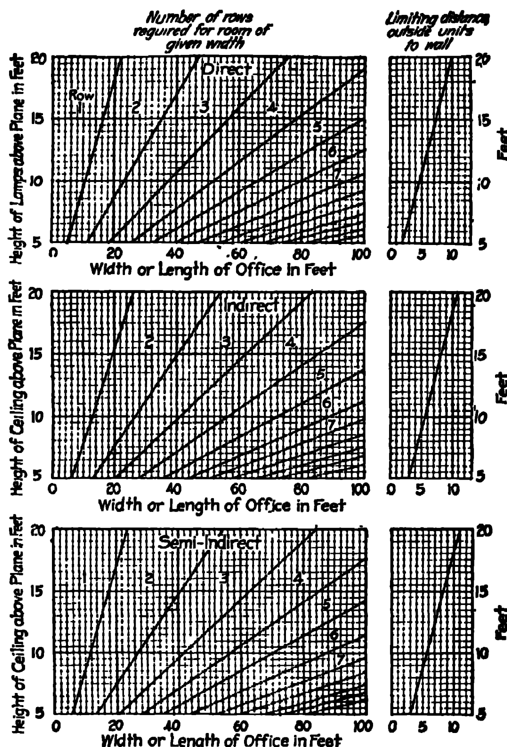
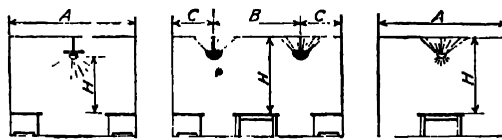


Fig. 25.

Table 8.—Maximum Ratios of Spacing to Height of Light Source for Satisfactory Office Illumination



System	Limits for one row of units $\frac{A}{H}$	Limits for more than one row of units $\frac{B}{H}$	$\frac{C}{H}$
Indirect	1.3	1.5	0.6
Dense semi-indirect*	1.2	1.5	0.6
Direct semi-enclosing	1.1	1.4	0.5
Direct dense opal	1.1	1.4	0.5

* With indirect or semi-indirect the ceiling is considered the light source.

Illustrative Problem.—It is necessary to design a lighting system for an office 20 × 40 ft. with 15-ft. ceiling. The ceiling is light but the walls are of moderate reflecting power, medium color. A totally indirect lighting system is to be used.

Assuming the working plane to be 30 in. ($2\frac{1}{2}$ ft.) from the floor, $H = 15 - 2\frac{1}{2} = 12\frac{1}{2}$ ft. According to the chart the number of rows of lamps for an office 20 ft. wide is 2, and for an office 40 ft. wide, the number of rows is 3. According to the small chart at the right, the maximum distance the units should be from the wall is 7 ft. The number of units for uniform illumination is 6, two rows of three lamps each. The lamps may be located 5 ft. from the side walls and 10 ft. apart across the room, and 6 ft. from the end walls and 14 ft. apart lengthwise of the room. Table 4 gives 3.5 to 5 ft.-candles as desirable illumination intensity for a general office. Assuming 5 ft.-candles for the illumination intensity, the lumens required are

$$\text{Lumens} = \frac{(20)(40)(4.5)}{0.26} = 13,800$$

Assuming a depreciation of 25% the total number of lumens necessary is

$$\tfrac{4}{3}(13,800) = 18,400$$

Since there are 6 units, each will have to generate 18,400 ÷ 6 = 3100 lumens, approximately. The 200-watt type C lamps generate 2920 lumens and should therefore prove satisfactory. If daylight illumination is desired, 300-watt type C-2 lamps should be used.

16. Industrial Lighting.—"Insufficient and improperly applied illumination is a prolific cause of industrial accidents."[1] To prevent these accidents as well as to protect the eyes from the injurious effect of improperly applied illumination, many states have by legislation provided that the industrial commission, or other bodies, fix standards of illumination and formulate rules relative to the enforcement of such standards. These rules are primarily concerned with the insidious effects of dim illumination, of glaring light sources, of flickering light, of sharp shadows, of glare caused by reflected light from polished surfaces, etc.

For satisfactory illumination by artificial light, the Industrial Commission of Wisconsin specifies that the light shall be supplied and maintained in accordance with Table 9.

A more detailed table[2] of illumination intensities has been compiled by C. E. Clewell from various authoritative sources. These data are given in Table 10.

Table 9.—Illumination Intensity at the Work in Foot-candles

	Minimum permissible intensity	Ordinary practice
(*a*) Roadways and yard thoroughfares	0.02	0.05 to 0.25
(*b*) Storage spaces	0.25	0.5 to 1.0
(*c*) Stairways, passageways, aisles	0.25	0.75 to 2.0
(*d*) Toilets and washrooms	0.5	1.5 to 3.0
(*e*) Rough manufacturing such as rough machining, rough assembling, rough bench work, foundry floor work	1.25	2.0 to 4.0
(*f*) Rough manufacturing involving closer discrimination of detail	2.0	3.0 to 6.0
(*g*) Fine manufacturing such as fine lathe work, pattern and tool making, light colored textiles	3.0	4.0 to 8.0
(*h*) Special cases of fine work, such as watch making, engraving, drafting, dark colored textiles	5.0	10.0 to 15.0
(*i*) Office work such as accounting, typewriting, etc.	3.0	4.0 to 8.0

Note.—The minimum foot-candles specify the lowest illumination intensity with which the employes can be expected to work with safety when artificial light is used. It is to the advantage of the employer to provide the intensities of ordinary practice, as this results in less eye strain, greater accuracy of workmanship, increased production for the same labor cost, less spoilage. When part daylight and part artificial illumination must be used together, it is desirable to employ even higher intensities than those of ordinary practice in the table above.

In order that the illumination intensities will never fall below the minimum during the interval between inspections, installations should be designed to produce initial values at least 25% higher.

[1] Industrial Commission of Wisconsin.

[2] C. E. Clewell, Lighting of Factories, p. 530, Illuminating Engineering Practice.

TABLE 10.—INTENSITIES OF ILLUMINATION RECOMMENDED FOR VARIOUS CLASSES OF WORK

	Foot-candles
Bakery	2.0 – 3.0
Bench work:	
Rough	1.5 – 5.0
Fine	3.5 –10.0
Box factory	2.0 – 4.0
Book binding:	
Cutting, punching, stitching	3.0 – 5.0
Embossing	4.0 – 6.0
Folding, assembling, pasting	2.0 – 4.0
Candy factory	2.0 – 4.0
Canning plants:	
Coffee roasting at tables	3.0 – 4.0
Filling tables	1.0 – 1.5
Packing tables	1.0 – 2.0
Packing tables (dried fruits)	1.5 – 2.5
Preserving cauldrons	2.0 – 2.5
Pressing tables	1.0 – 1.5
Shipping room	1.5 – 2.5
Cotton mill weaving	2.0 – 4.0
Dairy or milk depot	2.0 – 4.0
Drafting room	7.0
Electrotyping	3.0 – 6.0
Factory:	
Assembling	4.0 – 7.0
Drills	2.0 – 4.0
Millers	3.0 – 6.0
Planers	3.0 – 5.0
Rough manufacturing	1 25– 3.0
Fine manufacturing	3.5 – 6.0
Special cases of fine work	10.0 –15.0
Forge and blacksmithing:	
Ordinary anvil work	2.0 – 4.0
Machine forging	2.0 – 3.0
Tempering	2.0 – 4.0
Tool forging	3.0 – 5.0
Foundry:	
Bench moulding	1.0 – 3.0
Floor moulding	1.0 – 2.0
Garment industry:	
Light goods	3.0
Dark goods	7.0
Glove factory:	
Cutting	5 0 – 6.0
Sorting	6.0 –10.0
Hat factory:	
Blocking	4.0 – 6.0
Forming	3.0 – 5.0
Stiffening	2.0 – 4.0
Jewelry manufacturing	3.0 – 8.0
Knitting mill	3.0 – 6.0
Laundry	3.0 – 5.0
Leather working:	
Cutting	4.0 – 6.0
Grading	6.0 – 8.0
Meat packing:	
Cleaning	2.0 – 3.0
Packing	2.0 – 4.0
Offices	3.0
Packing and shipping:	
Ordinary work	2.0 – 3.0
Fine work	2.0 – 5.0

Paint shop:	
Coarse work (first coats)	2.0 – 4.0
Fine work (finishing)	4.0 – 8.0
Passageways	0.25– 0.5
Pattern shop (metal)	4.0 – 6.0
Pottery:	
Grinding	1.0 – 2.0
Pressing	2.0 – 4.0
Power house:	
Boiler room	0.8 – 1.5
Engine room	2.0 – 3.5
Preserving plant:	
Cleaning	2.0 – 4.0
Cooking	2.0 – 3.0
Printing:	
Presses	3.0 – 5.0
Type-setters	6.0 – 8.0
Sheet metal shop:	
Assembling	2.0 – 4.0
Punching	3.0 – 6.0
Shoe shops:	
Bench work	2.0 – 5.0
Cutting	5.0 – 7.0
Silk mill:	
Finishing	3.0 5 0
Weaving	4.0 – 6.0
Winding forms	2.0 – 4.0
Stairways	0.25 0.5
Steel work:	
Blast furnace (cast house)	0.3 – 0.5
Loading yards (inspection)	0.3 0.5
Mould, skull cracker and ore yards	0 1 0 3
Open hearth floors (soaking pits and cast house)	0 1 - 0.3
Rolling mills	1.0 – 2.0
Stamping and punching sheet metal	2.0 – 5.0
Stock room	0.8 – 2.0
Threading floor of pipe mills	1.0 - 2.0
Transfer and storage bays	0.5 1.0
Unloading yards	0 1 - 0.3
Warehouse	0.5 – 1.0
Stock rooms:	
Rough materials	1.0 – 3.0
Fine materials	2.0 – 4.0
Storage	0.25 - 0.5
Wire drawing:	
Coarse	2.0 – 4.0
Fence machines	2.0 – 5.0
Fine	4.0 – 8.0
Wood working:	
Rough	2.0 – 4.0
Fine	3.0 – 5.0
Woolen mill:	
Picking table	2.0 – 4.0
Twisting	2.0 – 3.0
Warping	3.0 – 5 0
Weaving	4.0 – 0 6

16a. Height of Lamps.[1]—The rules for mounting height given in preceding sections also apply in industrial lighting. It may, however, be stated that for direct lighting, the lamps should be mounted as high as possible. The chief exceptions to this rule are those cases where the ceiling is very high relative to one dimension of the floor and where beams, belting, or the like obstruct the light at some distance below the ceiling.

[1] Industrial Lighting Code—Industrial Commission of Wisconsin.

There are two chief advantages of mounting lamps as high as possible: (1) wide spacing of lamps with equally good distribution of light; and (2) the lamps are less likely to come within the direct range of vision, and hence are less likely to be a source of eye fatigue and eye strain to the worker.

16b. Spacing and Size of Lamps.—To facilitate the design of lighting systems, the chart (Fig. 26) was prepared by Arthur J. Sweet, and is included in the Wisconsin Industrial Lighting Code. The left-hand portion of the chart is for determining the spacing of the lighting units and the right-hand portion for determining the size of lamps. The illumination plane on which the curves are based is assumed to be 3 ft. above the floor but the data are sufficiently accurate for a working plane 2½ ft. above the floor. In using the chart the first step is to assume the mounting height of the light source above the working plane. Assume this to be 12⅓ ft. for a particular case. Referring to the left portion of the chart, the fine vertical line corresponding to 12⅓ ft. is followed to its intersection with the horizontal lines. Following the

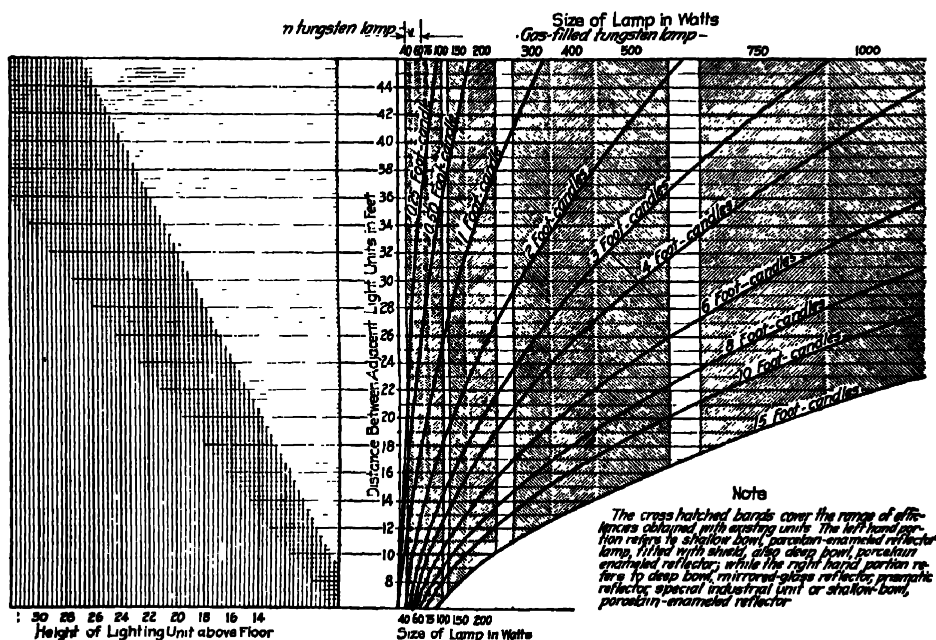


Fig. 26.

horizontal lines from the points of intersection to the vertical or spacing scale, it is found that the minimum spacing is 11 ft. and the maximum spacing is 17⅓ ft The best spacing will be the minimum of these values, namely, 11 ft. The exact spacing to be used in any case will depend upon the architectural features of the interior and the character of the work. If the work is of an exacting or close character, the spacing should approximate the lower limit. If the work is not of an exacting nature a wider spacing may be employed. If the factory building has bays 22 × 26 ft., the spacing should be 11 ft. in one direction and 13 ft. in the other direction, the average spacing being 12 ft. If the illumination intensity required is 4.00 foot-candles, then referring to the right-hand portion of the chart, the horizontal line corresponding to a spacing of 12 ft. is followed to its intersection with the curve representing 4.00 foot-candles. It is found that this occurs in the band representing the 100-watt lamp. This means that if the more efficient types of reflector be employed, the 100-watt lamp on an 11 × 13-ft. spacing will produce an average illumination slightly greater than 4.00 foot-candles. If, however, the less efficient types of reflector be employed, the 100-watt lamp will produce an illumination not

quite so great as 4.00 foot-candles. If it is desired to secure an illumination of not less than 4.00 foot-candles, the 100-watt lamp may be employed with one of the more efficient types of reflector or the 150-watt lamp with one of the less efficient types. The charts allow a depreciation of 30% due to dirt on reflector and lamp and deterioration of lamp filament.

The chart is for horizontal illumination only. If the work be chiefly in the horizontal plane, the charts may be used directly to determine the proper size of lamp with reasonable accuracy. If, however, the work be chiefly in some vertical plane, the problem becomes more complicated and can be solved only with rough approximation by any general data. The ratio between the horizontal and vertical illumination depends chiefly upon two factors: position of lamp with reference to the work, and type of reflector used. The first of these factors so depends upon local conditions that no data of value can be given thereon. As for the second factor, the approximate ratio between the vertical and horizontal illuminations is given for various types of reflectors in Table 11.

Table 11.—Approximate Ratio between the Vertical and the Horizontal Illumination

Type of reflector	Vertical illumination in per cent of horizontal illumination	Correction factor to be applied to size of lamp when Plate I is used for vertical illumination determination
Deep-bowl prismatic-glass reflector—special industrial unit.	100	1.0
Shallow-bowl porcelain-enameled metal reflector	70	1.4
Deep-bowl mirrowed-glass reflector	60	1.7
Shallow-bowl porcelain-enameled reflector—lamp fitted with shield or cap	55	1.8
Deep-bowl porcelain-enameled metal reflector	50	2.0

17. Residence Lighting.[1]—In addition to the general principles of illumination design, there are some specific factors which should be considered. As in other installations, the utilitarian and hygienic factor should take precedence, but in addition, the artistic features are also of great importance and should receive commensurate consideration. The following synopsis of the illumination requirements of different rooms of a residence in connection with Table 4 will be of assistance in planning a lighting system for a residence.

Living Room. The living room is the one room of the house which ought to be most comfortable and reposeful. The illumination requirements for such conditions are severe. The ceiling fixture provides a general illumination which is desirable and necessary for certain occasions. On other occasions a local illumination is a welcome relief just for the variety and change which it gives, and from an artistic viewpoint the glow of light from a few table lamps with uncertain grades of light and shadow intervening, entirely changes the expression of a room making it more livable and desirable, and it is here that the lamp itself as an artistic symbol becomes a part and feature of a home. To make possible this variety in illumination there should be several side-wall outlets, one or more ceiling outlets, and two or more baseboard receptacles to provide connections for electroliers, piano lamps, or other devices. The ceiling and side-wall lights can be most conveniently controlled by side wall switches placed beside the door through which entry is most often made.

Lower Hall.—The illumination requirements of halls are not so severe. The fixtures should, however, be in harmony with the other features of the hall and should possess some artistic merit. The outlets should be located so that all parts of the hall may be properly illuminated. Both the porch light and the hall light should be controlled by switches near the front door. The lights of both lower and upper halls should be controlled by three-way switches in order that the lower hall may be illuminated from the head of the stairs and the upper hall may be illuminated from the foot of the stairs. The stairway should in every case be well illuminated.

[1] The Electrical Equipment of a Home issued by National Electrical Contractors Association, National Electric Lamp Association, National Electric Light Association.

Porch.—A porch light should be installed just outside the entrance door so that it will illuminate the steps and the features of the caller without dazzling the eyes of one standing within. Other lights should be provided when the porch is of such size that good illumination cannot be provided from one outlet.

Reception Room.—The first impressions of a house are made by the reception room. Here the artistic features should be especially emphasized. The illumination as well as the location of the lighting units must depend upon the character of the room itself. A ceiling outlet should be provided for general illumination and in addition baseboard receptacles for the connection of a decorative electrolier.

Library.—The general illumination of the library should be by soft light of harmonious tone. Baseboard receptacles should be provided at several sides of the room to permit of the use of portable reading lamps.

Dining Room.—In the dining room the illumination is most effective if provided by a central ceiling outlet so that a strong mellow light is shed over the table from a dome or shower fixture. This may be supplemented by side-wall fixtures if the size of the room makes it advisable. The central lights should be controlled by a switch near the pantry door. It is very convenient also to have the interior of the china closet illuminated by small low-voltage lamps which may be operated by a separate transformer which is connected in such a way that the opening of the doors turns on the lamps.

Kitchen.—The illumination of the kitchen should be given careful consideration. Here the utilitarian features should be given precedence. There should be sufficient general illumination to make the objects of the room distinctly visible. In addition, local illumination should be provided for the stove, sink, and work table. A fixture in the center of the ceiling will usually suffice for the general illumination, and auxillary side-wall outlets should be provided for the stove, sink, etc. These should be placed so as not to shine directly into the eyes when a person is working at the sink, or over the stove; likewise, reflection from the dishes should also be avoided.

Pantry.—Good illumination of the pantry is essential, and in general, one outlet in the center of the ceiling or symmetrically located with reference to the cupboards, will be sufficient. The lamps should be placed high and equipped with a reflector that gives a wide distribution of light.

The Laundry.—The illumination of the laundry should be wholly general but the lamps should be so located that the light is concentrated on the ironing board and enough is shed into the closet where the laundry utensils are stored.

Upper Hall. The lighting of the upper hall requires simply a soft general illumination. This may be provided by either ceiling units, side-wall units, or both. The lamps should be located so that the head of the stairs is well illuminated. A turn down lamp near the head of the stairs is a great convenience for it may be burned dimly throughout the night. Three-way switches at the head of the stairs and near bedroom doors should be provided for controlling the upper hall lights; another three-way switch at the head of the stairs should be provided for operating the lamps in the lower hall.

Bedroom.—If the room is large, a central ceiling fixture should be installed for general illumination and bracket wall outlets should be provided for illuminating the dressing table, chiffonier, writing desk, and at the head of the bed. If it is inconvenient or too expensive to provide enough side-wall fixtures to insure perfect illumination, baseboard receptacles should be so placed that portable lamps may be used where necessary. In some cases, the switches for controlling the lamps on the lower floor are installed inside the entrance door of the master's bedroom. This lighting switch is a most effective protection against burglars and is especially desirable in suburban houses.

Bathroom.—The lighting of the bathroom should insure a strong light on the face from both sides of the mirror for convenience in shaving. This will necessitate two lamps which may be sufficient general illumination An additional ceiling light may be installed, however. This should be controlled by a switch near the door. Care should be taken so that the bath tub is not between the light sources and the window.

Sewing Room.—The sewing room can best be served by side-wall brackets so placed that they direct the light on the sewing machine and table. Glare should be avoided as well as specular reflection from the polished parts of the machine. The location of the lamps should be determined by the location of the sewing machine, windows, and other features.

Nursery.—The illumination of the nursery should be mainly general and uniform although some provision should be made at one or two convenient places for reading. The general tone of the illumination should be cheerful. These requirements can be fulfilled by a central ceiling fixture and one or more wall units.

Large Closets.—Large closets should be provided with a lamp directly over the door in a horizontal position or up against the ceiling. It should never be placed in a position such that inflammable material may be placed against it. This lamp may conveniently be controlled by a door switch. It is always advisable, however, to equip the lamp with a pull chain socket in order that the lamp may be turned off in case the door is to be kept open any length of time.

Attic.—The shape, size, and use of the attic will determine the number and location of lamps. Only general illumination of low intensity will usually be required. The lamps should be controlled by a switch near the foot of the attic stairs.

Cellar.—The cellar should be provided with sufficient light to make it bright and safe in every part. The greatest necessity, however, is proper illumination on the cellar stairs, before the furnace, in the fruit room, and at the ice box if it is located in the basement. The cellar lights should all be controlled by a switch at the head of the cellar stairs.

18. Natural or Daylight Illumination. In making provision for daylight illumination, the engineer or architect has no control of the light source and furthermore, he must adopt the building to the surroundings. The brightness of the sky varies from month to month and from hour to hour on normal days by several hundred per cent, while on many days it will vary by 50 to 100% in the course of a few minutes. Such conditions make the design of a natural lighting system difficult. Were it not for the fact that the eye has been developed to suit daylight the problem would be much more intricate. The main elements of the problems of daylight illumination may be briefly stated as follows:[1]

1. The determination of the minimum intensity of natural illumination below which artificial illumination becomes preferable.
2. The determination of the minimum ratio of the inside illumination to sky brightness which will produce the minimum illumination desired.
3. The minimum angle which a line from the top of a window makes with the horizontal at a given point in the room, or the relation between the light of the window head and depth of the room for reasonably good lighting.
4. The width and distribution of window glass essential for proper illumination at a given point in the room.

Many attempts have been made to specify the details of the elements of the problem mentioned in the foregoing; the different rules advocated, however, seldom agree with each other. The essentials of good natural illumination specified by different authorities are nevertheless of value for they may serve as criteria for judging the adequacy of a lighting system rather than as definite specifications in their design.

18a. Minimum Illumination.—This requirement varies widely for different purposes and also for different persons. The human eyes through ages of the influence of sunlight have developed an adjustability to an extremely wide range of natural illumination intensities. A thousand foot-candles of daylight illumination are less trying to the eye than 10 foot-candles of artificial illumination. In general, it may be said that daylight illumination intensities should be from 2 to 3 times those recommended for artificial lighting for the same class of service. Photometric data are needed, however, before definite specifications can be formulated. An indication of good practice is shown by Table 12[2] which gives the average daylight illumination intensities in representative mnaufacturing plants. Each value given is the means of a number of observations made on both clear and cloudy days.

[1] P. J. Waldram, The Illuminating Engineer, vol. 7, p. 23.
[2] Ward Harrison, Trans. Ill. Eng. Soc., vol. 12, p. 419.

TABLE 12.—WORKING INTENSITIES OF DAYLIGHT ILLUMINATION IN FOOT-CANDLES

Factory products	Grade of work		
	A	*B*	*C*
Engine lathes { Horizontal	10	7	3
Engine lathes { Vertical, Min.-Max.	6 15	2–15	0.5 9
Automatic engine lathes	14	12	10
	2 30	2–30	1 15
Machined forgings		6	5
		2-15	1–10
Special machinery	10	7	
	4 20	3-15	
Lamps	10	9	
	5 16	11–15	
Vacuum cleaners	17	11	
	7-25	3-20	
Automobiles	5	5	5
	2 11	2- 8	3–11
Automobiles*	10	3	5
	6-12	1 - 3	4– 5
Storage batteries		5	3
		1–6	0.5– 5
Machine tools and patterns	6	9	
	2–16	3-35	
Sheet iron equipment	10	5	8
	1-20	1 12	2–15
Machine gears	7	8	5
	3-16	5–18	1–15
Hardware	10	10	4
	1-20	1–20	0.5–12
Printing machinery		5	3
		1–15	0.5– 5
Sewing machines		4	2
		1–8	2- 5
Cloth bags		5	7
		3–10	3–10
Clothing	10	4	
	10 20	7-15	
Furniture	5	5	
	3–20	0.5 12	
Average	10	7	5
	1 18	3–15	1.5–10

*Saw tooth roof.

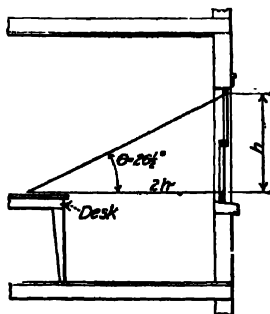


FIG. 27.

18*b*. Minimum Ratio of Inside to Outside Illumination.[1]– In offices and domestic apartments the requirements of ordinary comforts will not be infringed at any point where it is possible to read ordinary print at sunrise and sunset on a clear winter day. This gives an illumination of about 0.1% of the zenith sky, 0.2% of the average of the full hemisphere, and 0.4% of the illumination of a white card on the window-sill with an unobstructed horizon.

For schools, the desirable minimum is in the neighborhood of 2½ times as much as in offices. This means that the darkest desk should receive a minimum illumination equal to 0.25 % of the zenith, 0.5 % of the roof, light, or 1.0 % of the window-sill illumination with a free horizon.

[1] P. J. Waldram, Illuminating Engineer, vol. 7, p. 24.

19. Relative Value of Window Space in Different Positions.[1]—The data at present available give indications that the light entering a vertical window will not be effective in illuminating a table or desk at a greater distance from the window than twice the height of the top of the glass from the table or desk height (Fig. 27). This means that light entering at window is effective within the space lying below a plane which makes an angle of 26½ deg. with the horizontal. For schools, an angle of 30 deg. appears preferable. If the table is assumed to be 3 ft. above the floor, the relation between the window height and depth of room is shown in following table:

Height of top of glass above floor	Depth of room lighted (feet)
9	12
10	14
11	16
12	18
13	20
14	22
15	24

It is evident that in general the top of the window should be as close to the ceiling as practicable. The Industrial Commission of Wisconsin recommends that the top of the window be placed within 8 in. or less of the ceiling.

The window-sill should not be less than 3 to 3½ ft. from the floor.

20. Size and Location of Windows.—There is quite a discrepancy with respect to the relative areas of window space and floor area commonly recommended. For school lighting the ratio commonly specified ranges from ⅙ to ⅕. The Belgian government specifies ⅙ the floor area while Trucand Chavernace claims that ⅓ to ½ or even ⅔ of the floor area is the required window area. Engelbracht suggests the following formula:

$$w = \frac{A}{5} + \frac{d^2}{36}$$

where w = window area.
A = floor area.
d = depth of room.

This is perhaps the most reasonable requirement for it takes into consideration the depth of the room. For factories, offices, and buildings used for similar purposes, the order of the Wisconsin Industrial Commission specifies the glass area should equal 20% of the floor area, and the distance of any working position should not exceed 2.25 times the height of the top of the window above the floor where windows are on one side only, and 4.5 times this height where windows are on two sides. This differs slightly from the recommendation of Waldram as well as from that of Engelbracht. The differences are not great, however.

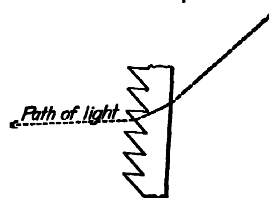


Fig. 28.

The importance of the location of windows is recognized by all authorities although there is a diversity of opinion in regards to details. They are all agreed that no windows should be placed where workers or pupils must face them. Since most persons are right-handed, one fundamental principle of proper lighting is to have light come from the left. In natural lighting three systems are in vogue: unilateral, bilateral, and sky-lighting. The predominant opinion favors unilateral lighting with the windows on the left of the pupils when seated. Prof. F. K. Richtmeyer recommends that windows be placed on only one side of school rooms less than 24 ft. wide, and bilateral lighting for wide rooms. H. L. Dunstall, an English architect, objects to bilateral lighting for it gives rise to conflicting shadows which are trying on the eyes. Where neighboring buildings obstruct the sky some form of prism glass may be used for the upper part of the windows (Fig. 28).

21. Natural Lighting of Factories.—The following more detailed specifications for natural lighting of factories are abstracted from the Industrial Lighting Code of the Industrial Commission of Wisconsin.

[1] P. J. Waldram, Illuminating Engineer, vol. 7.

21a. Window Frames.—The steel window frame has approximately 25% more glass area for the same window opening. Steel window frames are not subject to the effect of moisture, like wooden frames, hence their operation is certain. In extra large openings they can be reinforced to resist wind pressure or other strains without noticeable interference with the light area.

21b. Window Glass.—Both translucent and clear glass may be employed in industrial plants. For the upper and middle portions of the windows, clear glass is preferable especially where suitable window shades are provided. If no window shades are provided, moderately translucent glass can be employed to advantage in the lower portions of the windows to a distance of approximately 6 ft. from the floor.

Translucent wire glass, also called ribbed glass, in steel frames is often desirable for reducing the fire risk. The glass should be smooth on both sides to facilitate cleaning. It is best to install the glass with the ribs horizontal because the prism effect of the ribs will direct more light to the interior of the building.

21c. Window Shades.—When clear window glass is used, shades may be required to exclude direct sunlight. The best method of accomplishing this result is to employ two shades—a very translucent shade which can be pulled down from the top, and a much denser shade, but yet translucent shade, which can be pulled up from the bottom. If only one shade is used, it should be mounted at the bottom of the window and should be the dense, slightly translucent shade mentioned above.

21d. Bench Location.—Considerations of good illumination require that work benches, desks, etc., be located perpendicular to the windows (Fig. 29). With such an arrangement the effects of shadows and glare are practically eliminated.

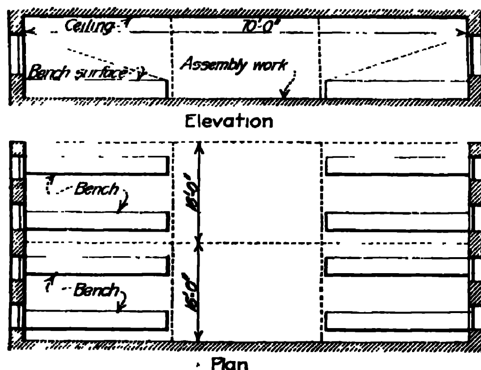


Fig. 29.

21e. Skylights.—Skylights may be of two kinds depending upon the form of room construction—flat or monitor. When flat skylights are employed, the ribs of wire glass should be installed so that the ribs run parallel to the long dimension of the skylight. If this is not done, the light is diffused over a narrow area parallel to the strip of skylight thus lighting one part of the room much more brilliantly than the remainder, which condition it is desirable to avoid.

The illumination near the center of the top floor may be made satisfactory by the use of flat skylights. Too strong light during parts of the day is the chief disadvantage of this system.

21f. Monitor Roof Skylights.—This type of construction is shown in Fig. 30. To make this method most effective the ceilings and upper walls must be finished white. A special form of monitor roof skylight is the so-called saw-tooth construction (see Fig. 31). With this construction a nearly uniform intensity and excellent diffusion of illumination is

secured throughout the work space. It is more adaptable for lighting large floor areas in wide buildings with low ceilings than the monitor skylight. The windows of the skylight should face north or as nearly so as possible. The saw-tooth skylight is especially well suited for lighting textile mills, machine shops, foundries, drafting rooms, and dye houses where careful color matching is done.

Since the saw-tooth windows should face north, they should be inclined at an angle of 20 to 30 deg. from the vertical in order to admit some light from the upper sky, and to avoid one skylight cutting off the light from the next in the rear. The interior surfaces of the saw-tooth should be painted white to diffuse the illumination The angle at the peak of the saw-tooth should be approximately 90 deg.

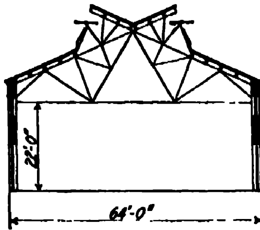


Fig. 30.

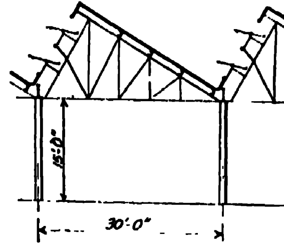


Fig. 31.

Shades will scarcely ever be r l with the saw-tooth skylight when they face north except in some offices. The illumination of vertical surfaces facing the skylights will be higher than the illumination on vertical surfaces facing in the opposite direction; hence, where stron umination on a vertical plane is necessary the work should be arranged accordingly. The horizontal illuminati can be made practically uniform.

Before designing an illumination system for a building, it is advisable to consult the latest bulletins of the Engineering Department of the National Lamp Works, Nela Park, Cleveland, Ohio. These bulletins contain the latest data on lamps, shades, globes, and other lighting equipment as well as the latest developments in the lighting art.

SECTION 8

GAS LIGHTING

By C. M. Jansky

With the invention of the incandescent electric lamp, the use of gas for lighting rapidly declined, but with the invention of the gas mantle and the greater improvement in gas lighting fixtures, gas again became a strong competitor of electricity in the field of illumination. In many cases the designer of a lighting system will do well to consider the possibilities of gas lighting service. The installation costs of a first-class gas and a first-class electric lighting system are approximately the same, while in some instances the cost of operation may be less for gas than for electricity.

The general principles of calculating the illumination produced by a gas lighting system are the same as those for electric lighting. The difference lies in the character of the distribution curves and variations in the light flux of the gas lighting units.

1. Definitions.—*Gas Pressure.*—Gas, like any other fluid, will flow through pipes only if there is a difference of pressure between any two points along the pipes. This difference in pressure is indicated by the height of a column of water supported by the pressure of the gas, which is obtained by measuring the difference between the levels of a quantity of water in a U-shaped tube, one end of which is connected to the gas supply, the other being open to the air.

Since 1 cu. in. of water weighs 0.03613 lb., to determine the pressure of the gas per sq. in., merely multiply the difference in water level, that is, pressure in inches of water, by 0.03613. Sometimes the pressure is expressed in terms of the difference of elevation of mercury in the two limbs of a manometer tube. When this is done the water equivalent may be obtained by multiplying the mercury elevation by 13.56, since mercury is 13.56 times as heavy as water.

Density or Specific Gravity.—The specific gravity of gas means the relative weight of a volume of the gas and the weight of an equal volume of air at 32 deg. F. and 1 atmospheric pressure. Since illuminating gases are lighter than air, the specific gravity of the gas will almost invariably be less than unity.

Heating or Calorific Value.—With the introduction of the gas mantle the illuminating properties of a gas are no longer determined by its composition but by its heating value. The calorific value of a gas is the heating power of the gas expressed in British thermal units per cubic foot of the gas at a temperature of 62 deg. F., and under a pressure of 1 atmosphere, about 30 in. of mercury. One B.t.u. is the quantity of heat required to raise the temperature of one pound of water from 62 deg. to 63 deg. F. The heating value of the gas is determined by burning a quantity of it in such a manner that all the heat produced is transmitted to a known weight of water. By measuring the increase in the temperature of the water, multiplying this by the weight of the water, and dividing by the volume of the gas consumed, the result is the B.t.u. per cubic foot of the gas.

Gas Candles Power.—Although the quality of gas is still sometimes expressed in terms of its candle power, the luminous property is of little practical importance. The candle power of a gas is the luminous intensity in a horizontal direction from an Argand burner or from the flat side of an open tip burner consuming 5 cu. ft. of gas per hr., and is obtained by direct comparison with a standard of known intensity. It is an indication of the amount of illuminants in a gas. With the mantle, the candle power is not determined by the illuminants but by the heating value. The gas is thus merely a fuel for raising to incandescence the material of the mantle.

Gaseous Fuels.—The gases used for both illuminating and heating purposes may be divided into two general classes, manufactured and natural. The chemical composition of gases in either of these classes will vary and accordingly the heating values will vary. Table 1 gives the composition of manufactured commercial gases.

TABLE 1.—COMPOSITION AND HEATING VALUE OF COMMERCIAL GASES

Character of gas	Hydrogen, H_2	Methane, CH_4	Ethylene, C_2H_4	Nitrogen, N_2	Carbon monoxide, CO	Oxygen, O_2	Carbon dioxide, CO_2	B.t.u per cu. ft.	Authority
Oil gas	32.0	48.0	16.5	3.0	....	0.5	....	840	Wyer, S. S.
Coke-oven gas	50.0	36.0	4.0	2.0	6.0	0.5	1.5	603	Wyer, S. S.
Carbureted water gas	40.0	25.0	8.5	4.0	19.0	0.5	3.0	575	Wyer, S. S.
Water gas	48.0	2.0	..	5.5	38.0	0.5	6.0	295	Wyer, S. S.
Blast-furnace gas	1.0	..	....	60.0	27.5	...	11.5	91	
Pintsch gas	12.4	45.4*	35.7†	3.0	0.6	2.0	0.7	1500	

* Saturated hydrocarbons. † Unsaturated hydrocarbons.

In addition to the gases mentioned in the above table, two other gases should be mentioned—coal gas and acetylene. The composition of coal gas will depend upon the quality of the coal from which it is made. The heating value will range from 500 to 678 B.t.u. per cu. ft. Acetylene is a gas rich in carbon and must be burned with a liberal supply of air, but when so burned gives a very brilliant whitish flame and produces a most useful local source of light. A mantle is seldom used with an acetylene burner, hence its heating value for illumination is immaterial although it will develop between 1437 to 1477 B.t.u. per cu. ft. Natural gas, like coal gas, will vary greatly in composition depending upon the locality of the wells. Its specific gravity ranges from 0.57 at Clarion Co., Pa., to 1.01 in northwestern Oregon.[1] The heating value ranges from 21 to 1766 B.t.u. per cu. ft.

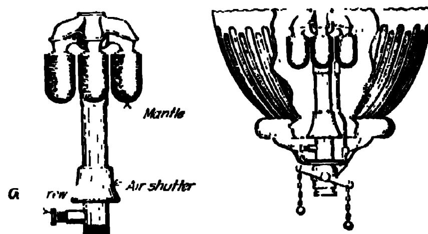


FIG. 1.

2. Gas Lamps.—The gas lamp in its simplest form consists of two essential parts—the burner and the mantle—the former usually being fitted with a glass chimney to secure satisfactory and efficient illumination (Fig. 1). The function of the burner is to properly mix the air and gas and to direct the flow of the mixture so that when ignited it will raise the mantle to a uniformly high temperature. The luminous property of the burning gas is of no importance but its heating properties are of first importance. The mantle is a lacelike hood of refractory material which, when heated to incandescence, gives a brilliant light. The mantle is made of some organic material, such as "artificial silk," impregnated with the salts of ceria and thoria. The character

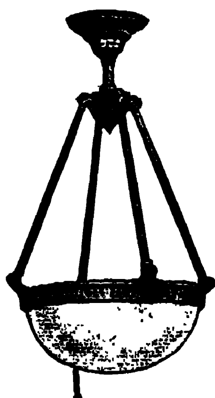


FIG. 2.



FIG. 3.



FIG. 4.

[1] Marks, Mechanical Engineers' Handbook, p. 614.

of the fabric used determines the mechanical strength of the mantle, while the rare earths employed determine its radiant efficiency and the color of the light. In the earlier lamps the mantle was mounted above and enclosing the burner. This greatly limited the use of the gas lamp, but more modern designs permit the mounting of the mantle below the burner in a pendant position.

Likewise, the lamps may be single or multiple, *i.e.*, contain one or more burners and mantles. With these developments, the gas lamp has almost the same adaptableness as the electric lamp. Some recent types of inverted gas lamps are shown in Figs. 2, 3, and 4.

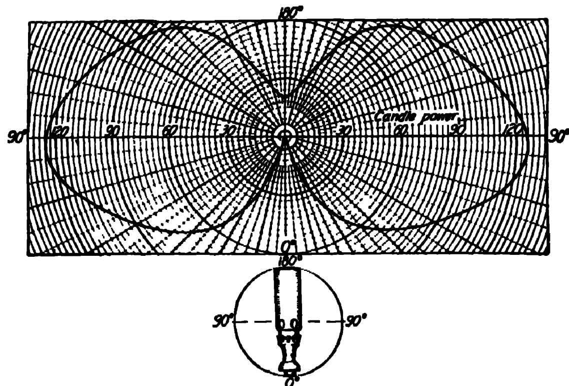


Fig. 5.

3. Distribution Curves.—The light flux distribution curve of the gas lamp depends upon the reflector in the same manner as the distribution curve of an electric lamp. This is shown by Figs. 5 and 6. Fig. 5 is the distribution curve of a vertical gas lamp consuming 4.66 cu. ft. of water gas per hr. with a clear chimney. Fig. 6 is the distribution curve of a similar lamp with a reflector as shown. It is thus evident that in designing a gas lighting system, due attention must be given to the type of reflector and the distribution curves produced.

4. Design of Gas Lighting System.—The first step in designing a gas lighting system is exactly the same as for an electric lighting system; that is, the determination of the proper illumination on the working plane. The second step is the calculation of the number of lumens necessary to produce this desired illumination. The number of lumens emitted by any lamp may be calculated from the distribution curve of that lamp. If the mean spherical candle power of the lamp is known, the total lumens may be obtained by multiplying the mean spherical candle power by 12.57. It is rather difficult to follow this procedure for the coefficients of utilization for gas lighting fixtures are not available. Table 2[1] gives much valuable data on gas lamps and reflectors. This together with Table 3 may be used in determining the spacing and mounting height of different types of lamps of the Welsbach make. The radius for 4-foot candles illumination, Table 2, is the radius of the horizontal circle on the working plane from a point immediately beneath the lamp within which circle an average illumination of 4 foot-candles will be produced when the lamp is placed at the proper height. To find the corresponding radius for other illumination intensities, the radius for 4 foot-candles is multiplied by the multiplier, Table 3, opposite the desired illumi-

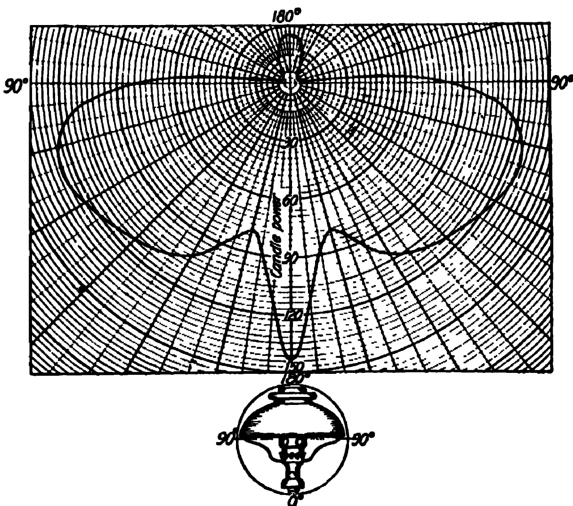


Fig. 6.

[1] Welsbach Illumination Data Book.

nation intensity. Opposite this corrected radius will be found the mounting height above the working plane. The zones 30, 45, and 60 deg. for which calculations are made, are those within which the light from the different reflectors is distributed with such uniformity upon a horizontal plane that the minimum illumination near the edge of the illuminated area will be near enough to the average for practical purposes. The zones are measured from the bottom of the vertical axis of the lamp.

Table 2.—Radius of Illuminated Area for 4-foot Candles Illumination with Different Lamps and Glassware

Lamp	Mantle	Chim. or globe	Shade	Cons. (cu. ft.	60 deg. lumens	Radius for 4 f.-c. illum.
905	4-#2	434 alab.	#98 Opal	18.8	877.4	8 ft. 4 in.
905	4-#2	434 clear	#98 Opal	18.8	879.2	8 ft. 4 in.
209	4 reflex	10 clear		13.03	906.0	8 ft. 6 in.
209	4 reflex	10 alab.		13.03	730.0	7 ft. 8 in.
902	1 reflex	5 clear		3.71	328.0	5 ft 0 in.
901	1 reflex	5 clear		3.71	324.0	5 ft. 0 in.
1911	5 reflex	11 clear		17.01	1912.0	12 ft 6 in.
1911	3 reflex	12 clear		11.02	1245.0	10 ft. 0 in.
66	4197	306 clear	71 opal	5.12	430.7	5 ft 9 in.
71	197	306 clear	71 opal	4.66	321.0	5 ft 0 in.
71	197	306 clear	71 gr. opal	4.66	337.1	5 ft. 2 in.
71	197	306 opal	71 opal	4.66	302.0	4 ft 11 in.
71	197	42 ch.	71 opal	4.07	345.0	5 ft. 3 in.
71	197	42 ch.	71 gr.	4.07	280.0	4 ft. 9 in.
71	196	310 c. ch	316 op.	3.70	253.0	4 ft. 6 in.
71	196	310 op.	316 op.	3.70	230.0	4 ft 0 in.
52	53		1678	1.66	42.5	1 ft. 6 in.
1 reflex	reflex	317 TF	442 F. R.	3.31	217.4	4 ft. 2 in.
1 reflex	reflex	317 C.	441 V.K.	3.56	224.1	4 ft. 3 in.
1 reflex	reflex	317 H.F.	502 gr.	3.31	312.1*	5 ft. 0 in.
1 reflex	reflex	317 H.F.	531	3.31	264.8*	4 ft. 4 in.
1 reflex	reflex	317 H.F.	502 op.	3.31	231.8*	4 ft. 3 in.
1 reflex	reflex	317 T.F.	531	3.31	304.7*	4 ft. 11 in.
1 reflex	reflex	317 F.	504	3.31	210.3*	4 ft. 1 in.
1 reflex	reflex	317 H.F	504	3.31	234.0*	4 ft. 4 in.
1 reflex	reflex	317 F.	503 op.	3.31	326.0	5 ft. 0 in.
1 reflex	reflex	317 F.	533 en.	3.31	295.0	4 ft. 10 in.
1 reflex	reflex	317 H.F.	533 en.	3.31	321.0	5 ft. 0 in.
1 reflex	reflex	317 T.F.	E-1	4.20	538.9	6 ft. 6 in.
1 reflex	reflex	317 T F.	I-1	4.20	368.0*	5 ft. 4 in.
1 reflex	reflex	317 C.	F-1	4.20	292.0†	4 ft. 10 in.
1 reflex	reflex	317 T.F.	3416	3.65	344.0	5 ft. 3 in.
1 reflex	reflex	317 T.F.	1602	3.65	380.0	5 ft. 5 in.
1 reflex	reflex	317 H F	1602	3.65	344.0	5 ft. 3 in.
1 reflex	reflex	317 T F.	0918	3.74	424.0	5 ft. 9 in.
reflex-20	403	376 C.	224 op	8.69	1203.0	9 ft. 9 in.
reflex-20	403	376 C.	7150 holo.	8.69	1346.0	10 ft. 4 in.
reflex-20	403	376 C.	222 op.	8.69	1146.0	9 ft. 6 in.
reflex-20	403	376 C.	224 Al.	8.69	1097.0	9 ft. 4 in.
reflex-20	403	376 C.	248	8.69	1113.0	9 ft. 5 in.
reflex-20	403	376 C.	228 Op.	8.69	1016.0	9 ft. 0 in.
reflex-20	403	376 V.K.	244 Al.	8.69	883.0	8 ft. 3 in.
		376 V.K.	352	8.69	1077.0	9 ft. 3 in.
open flame	....	....	....	7.23	90.0	2 ft. 8 in.
intenso	3-Ref.	910 C.	....	10.62	912.0	8 ft. 9 in.
4 reflex	40	....	423 C.R	1.70	141.5	3 ft. 5 in.
4 reflex	40	328 T.F	9421	1.70	222.5	4 ft. 3 in.
48 reflex	3-33	8 C.	. ...	6.72	908.0	8 ft. 5 in.
48 reflex	3-33	8 Al.	....	7.21	638.0	7 ft. 1 in.
1800	3-33	1806 Al.	. ...	7.14	707.0	7 ft. 6 in.

* lumens in 45 deg. zone.
† lumens in 30 deg. zone.

TABLE 3

Illumination ft.-candles	Multiplier for radius	Corrected radius	Mounting height above working plane		
			60 deg.	45 deg.	30 deg.
1	2	2 ft. 6 in.	1 ft. 6 in.	2 ft. 6 in.	4 ft. 4 in.
1⅓	1¾	3 ft. 0 in.	1 ft. 9 in.	3 ft. 0 in.	5 ft. 3 in.
2	1⅖	3 ft. 6 in.	2 ft. 0 in.	3 ft. 6 in.	6 ft. 0 in.
2⅔	1¼	4 ft. 0 in.	2 ft. 4 in.	4 ft. 0 in.	7 ft. 0 in.
3	1⅐	4 ft. 6 in.	2 ft. 7 in.	4 ft. 6 in.	7 ft. 9 in.
4	1	5 ft. 0 in.	2 ft. 11 in.	5 ft. 0 in.	8 ft. 8 in.
5⅓	⅞	5 ft. 6 in.	3 ft. 2 in.	5 ft. 6 in.	
6	⅘	6 ft. 0 in.	3 ft. 6 in.	6 ft. 0 in.	
7	¾	6 ft. 6 in.	3 ft. 9 in.	6 ft. 6 in.	
8	7⁄10	7 ft. 0 in.	4 ft. 0 in.	7 ft. 0 in.	
		7 ft. 6 in.	4 ft. 4 in.	7 ft. 6 in.	
		8 ft. 0 in.	4 ft. 7 in.	8 ft. 0 in.	
		8 ft. 6 in.	4 ft. 11 in.	8 ft. 6 in.	
		9 ft. 0 in.	5 ft. 3 in.	9 ft. 0 in.	
		9 ft. 6 in.	5 ft. 6 in.	9 ft. 6 in.	
		10 ft. 0 in.	5 ft. 9 in.	10 ft. 0 in.	

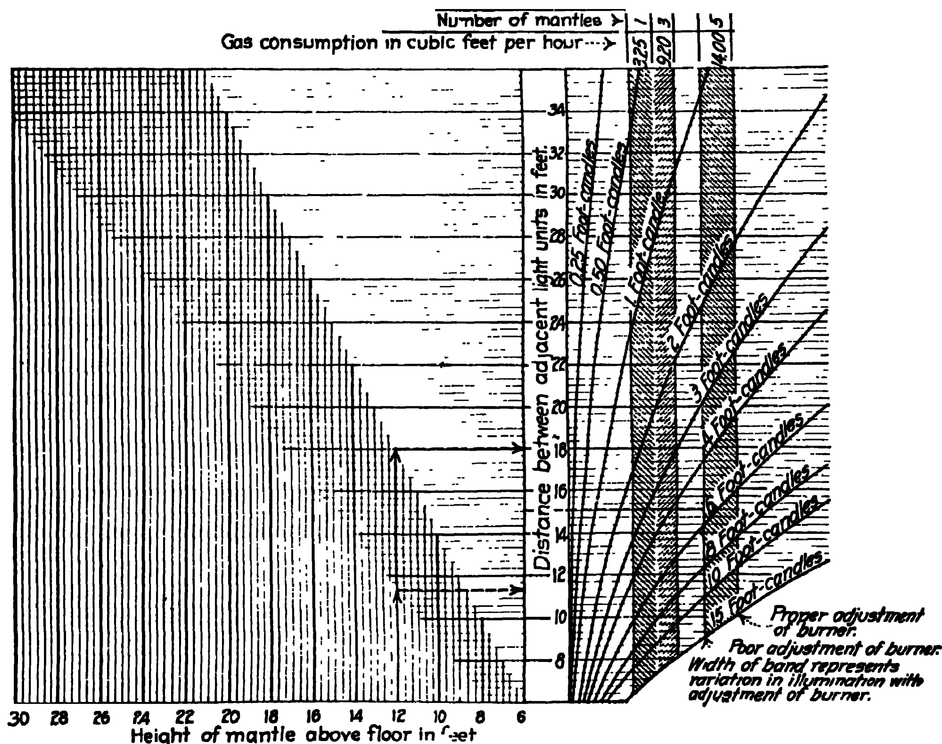


FIG. 7.

Illustrative Problem.—What must be the mounting height of a No. 20 Reflex lamp with a No. 248 reflector, in order to produce an average illumination of 6 foot-candles, and how far apart should the lamps be spaced?

By Table 2, the illumination radius for 4 foot-candles is 9 ft. 5 in. The multiplying factor for 6 foot-candles is 4/5, Table 3. The corrected radius is 4/5 × 113 in. = 92 in. = 7 ft. 8 in., practically, 7 ft. 6 in. Referring to Table 3 we find that for a 60-deg. zone, the mounting height is 4 ft. 4 in. and for a 45-deg. zone, it is 7 ft. 6 in. above the illumination plane. If the lamps are thus mounted 15 ft. apart, the illumination intensity will be about 6 foot-candles.

Arthur Sweet has prepared for the Industrial Commission of Wisconsin a chart, Fig. 7, for determining the proper spacing and size of gas lamps to produce a desired illumination intensity. This is used in exactly the same way as chart, Fig. 26, p. 1414. The result, however, is given in cubic feet of gas per hour required and number of mantles instead of watts.

Illustrative Problem.—An illumination intensity of 6 foot-candles is required. lamps are to be mounted 12 ft. above the floor. What is the minimum and m ximum spacing and what gas c mption will be required?

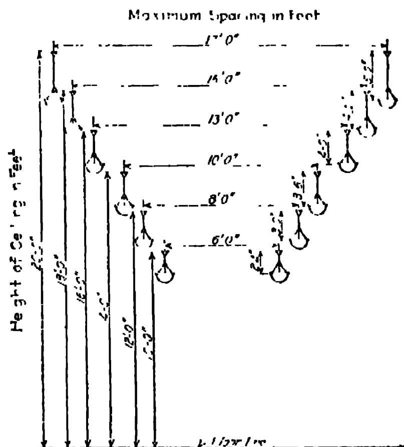


Fig. 8.

Referring to the chart, we see that the minimum spacing is 11 ft. 6 in. and maximum spacing 18 ft. The exact spacing in any case will depend upon local conditions. Assuming a spac f 15 ft., we find that the horizontal line corresponding to this spacing intersects the 6 foot-candle curve in the space corresponding to a 5-mantle 14 cu. ft. per hr. lamp. For a spacing of 13 ft., one 3-mantle 9.20 cu. ft. per hr. l p will give the desired illumination.

5. Semi-indirect Gas Illumination.—With the development of the inverted mantle, semi-indirect illumination was made possible. The problem of determining the location, spacing, height, and size of lamp for semi-indirect gas illumination is the same as for electric illumination. The coefficients of utilization are of about the same order of magnitude as for semi-indirect electric illumination—seldom will this be over 40%. The type of fixture, condition of reflecting surface of the reflector, and of the walls and ceiling, are important factors. Unless exact data are available, the light flux emitted by a burner consuming 1 cu. ft. of gas per hr. for indirect lighting may be assumed to be 250 lumens. With this data the size of lamps necessary can be determined with reasonably close approximation.

Illustrative Problem.—A store 25 × 50 ft. is to be illuminated by semi-indirect gas lamps. If the ceilings are 12 ft. high, how many, what size lamps are required, and how should they be spaced? The ceiling is white and walls are medium.

According to Table 1, p. 1321, the coefficient of utilization for a semi-indirect electric lighting system for a room of the size specified, is about 37%. Assuming the coefficient of utilization for gas lighting to be the same, and assuming 6 foot-candles to be the illumination intensity desired, the total lumens necessary equals

$$\text{Lumens} = \frac{25 \times 50 \times 6}{0.37} = 20{,}300$$

If each cubic foot of gas produces 250 lumens, then the gas required per hour equals 20,300 : 250 = 81, and assuming each burner to consume 3 cu. ft. per hr., the number of mantles required is 81 ÷ 3 = 27.

The spacing and height of ı nting is determined by the shape of the room and height of ceiling. Figs. 8 and 9[1] show maximum distances nissible between outlets. Since the ceiling is 12 ft. high, the maximum spacing, Fig. 8, is 8 ft. and Fig 9, 16 ft. ıe former is for rooms where close and exacting work is done. Requirements

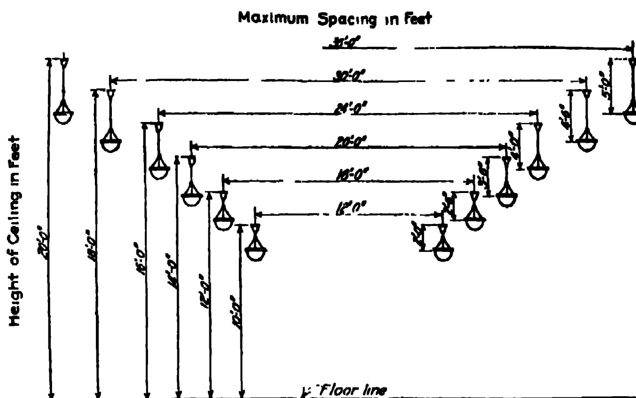


Fig. 9.

of symmetry require two rows of lamps 6 ft from the outside walls and 13 ft. apart The lamps in the rows may be 6 ft. from the end walls and 12 ft 8 in. apart. This necessitates 8 lamps of three burners each.

[1] Welsbach, "Short Cut Method of Calculating Illumination with Semi-indirect Fixtures."

SECTION 9

GAS FITTING

By C. M. Jansky

Gas used for heating, illumination, and other purposes is distributed through the buildings by means of wrought-iron or steel pipes which are coupled or connected by special parts called fittings. The term *pipe fitting* is used to designate the work of putting together various lengths of pipes and their connecting parts.

1. Gas Pipe.—Most of the pipe now used for the distribution of gas is made of a low-carbon acid Bessemer steel. This steel welds readily and it has nearly displaced wrought iron for this purpose. The seams of gas piping are welded by one of two methods: pipes of 1¼-in. diameter or under are butt welded, and those over 1¼-in. diameter are lap welded. Welded pipes may have defects and hence each piece should be carefully inspected before it is installed. The most common defects are:

1. *Defective welds*, that is, the seam may be imperfectly joined.
2. *Cracks.*—These originate in the ingot as blowholes, shrinkage cracks, or other defe: As the ingot i rolled out in a sheet these defects lengthen out.
3. *Blisters.*—These are caused by "piping," or cavity in the ingot, and heat swells thei above the surfac when the pipe is formed.
4. *Scale Pits and Sand Marks.*—These are small indentations caused by rolling scale or sand into the surfaces of the plate from which the pipe is formed.

Welded steel pipe is made in standard sizes designated in inches, as follows: ⅛, ¼, ⅜, ½, ¾, 1, 1¼, 1½, 2, 2½, 3, 3½, 4, 4½, and in sizes of even inches from 5 to 12 in. inclusive. These sizes refer to the inside diameters of the pipes, but as a matter of fact, they are only nominal as the actual diameters differ more or less from the designated diameters. While pipe is designated by its nominal inside diameter, it is standardized in size in outside diameters.

Steel pipe may be obtained either galvanized or plain, and some makers coat it with asphalt or tar. A pipe is now made particularly smooth and free from scale by welding it slightly over size and reducing it to proper dimensions in sizing rolls.

2. Dimensions of Standard Iron Pipes.[1] —The following table shows the standard dimensions of iron pipe, including standard threads for ends of the pipe. These standard sizes are made in wrought iron, mild steel, and brass as commerical products.

In ordering iron pipe it is necessary to designate only the size of pipe required as given in the first column of the table, without any mention of thickness.

Size (inches)	Actual outside diameter (inches)	Thickness (inches)	Threads per inch	Size (inches)	Actual outside diameter (inches)	Thickness (inches)	Threads per inch
⅛	0.405	0.068	27	3½	4.0	0.226	8
¼	0.54	0.088	18	4	4.5	0.237	8
⅜	0.675	0.091	18	4½	5.0	0.246	8
½	0.84	0.109	14	5	5.563	0.259	8
¾	1.05	0.113	14	6	6.625	0.280	8
1	1.315	0.134	11½	7	7.625	0.301	8
1¼	1.66	0.140	11½	8	8.625	0.322	8
1½	1.9	0.115	11½	9	9.625	0.344	8
2	2.375	0.154	11½	10	10.75	0.366	8
2½	2.875	0.204	8	11	11.75	0.375	8
3	3.5	0.217	8	12	12.75	0.375	8

[1] From Danforth's Mech. Process, p. 401.

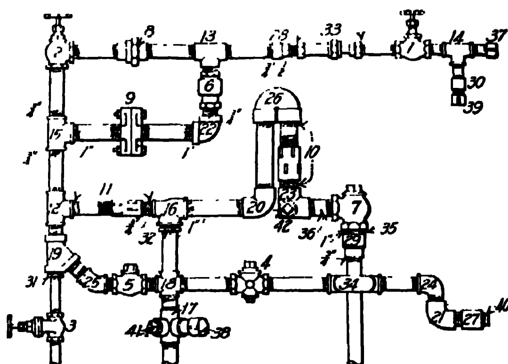


Fig. 1.—Examples of pipe fitting.

3. Pipe Fittings.—Pipe fittings are made in standard forms, sizes, and threads to agree with standard sizes of pipes. Fittings of one manufacture may thus be used with piping of another manufacture although difficulty is occasionally found in pipe-fitting due to the fact that the slightly tapered threads on both pipe and fittings are cut too deep or too shallow. Fig. 1 together with the explanatory table,[1] gives information concerning standard forms of fittings some of which are not common on gas installations.

Reference No.	Fitting	Size (inches)	Style
1	Globe valve	½	
2	Angle valve	¾	
3	Gate valve	½	
4	Plug cock	¾	
5	Horizontal check valve	¾	
6	Vertical check valve	¾	
7	Angle check valve	1	
8	Screw union	¾	
9	Flange union	1	
10	Long screw	1	
11	Long screw	¾	
12	Tee	¾	Malleable, beaded
13	Tee	¾	Malleable, plain
14	Tee	½	Malleable, beaded
15	Bull-head tee	¾ × 1	Malleable, beaded
16	Reducing tee	¾ × 1 × 1	Malleable, beaded
17	Four-way tee	¾	Malleable, plain
18	Cross	¾	Malleable, beaded
19	Y-branch	¾	Cast iron
20	Elbow	1	Malleable, plain
21	Elbow	¾	Malleable, plain
22	Reducing elbow	¾ × 1	Cast iron
23	Side-outlet elbow	1	Malleable, plain
24	Street elbow	¾	Malleable, beaded
25	45-deg. elbow	¾	Malleable, beaded
26	Return bend	1	Cast iron
27	Sleeve coupling	¾	
28	Reducing coupling	½ × ¾	Malleable, plain
29	Reducing coupling	¾ × 1	Malleable, plain
30	Extension piece	½	Malleable, plain
31	Bushing	½ × ¾	
32	Bushing	¾ × 1	
33	Expansion joint	½	
34	Cross-over	¾	Malleable, beaded
35	Shoulder nipple	1	
36	Long nipple	1	
37	Cap	½	
38	Cap	¾	
39	Cap	½	
40	Plug	¾	
41	Plug	¾	
42	Plug	¾	

[1] Danforth's Mech. Process.

Fittings are made of cast iron or malleable iron. The malleable iron fittings are adapted to high pressures. They are made in two styles known as beaded, that is, with a rolled rim at the opening; and plain, without a rim. Cast-iron fittings are more bulky than the malleable fittings and are used for pressures of not over 150 lb. Iron fittings are either black or galvanized. The latter should be used in connecting gas pipes.

4. Tools Used in Pipe Fitting.[1]—The hand tools ordinarily used in pipe work are shown in Fig. 2. The pipe vise holds pipe for cutting, threading, and fitting parts together. The tongs and wrenches grip the pipe for holding or turning. Dies, made with standard threads, are held in the die stock when in use. Each size of pipe die has a bushing which fits in the stock behind the die to steady the stock on the pipe end.

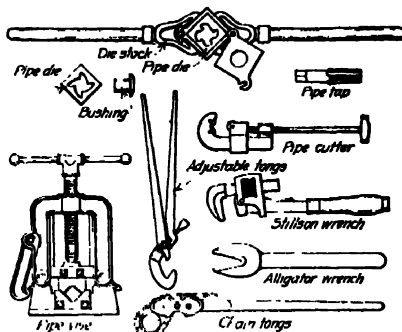


FIG. 2.—Pipe fitting tools.

5. Flow of Gas in Pipes. In order that the gas appliances may operate at maximum efficiency they must be supplied by the proper amount of gas at the proper pressure. This means that the pipes must be of ample size so that the pressure will not be materially reduced. The size of the pipe will depend upon the number of outlets to be supplied and the length of pipe.

The standard formula for calculating the size of pipe is that of Prof. Pole as follows:

$$d = \sqrt[5]{\frac{Q^2 L \rho}{C^2 (P_1 - P_2)}}$$

in which d = diameter of pipe, in inches.
Q = cubic feet of gas per hour.
P_1 = initial pressure, inches of water.
P_2 = terminal pressure, inches of water.
L = length in feet.
ρ = specific gravity of gas, air 1.
C = constant = 2310, about.

Experience, however, shows that the actual diameter should be considerably larger than the theoretical diameter given by Pole's formula. Furthermore, allowances must be made for partial obstruction of the pipe due to rust and condensed hydrocarbons. This allowance should be about one-third for smooth lead pipes and one-half for iron pipes.[2]

Illustrative Problem.—What size pipe is necessary to supply five burners, each consuming 4 cu. ft. of gas per hr., if the difference of pressure is 1 in. of water? The density of gas is 0.45, and the distance of burners from main is 50 ft.

Data:

$$Q = 4 \times 5 = 20 \text{ cu. ft.}$$
$$L = 50 \text{ ft.}$$
$$\rho = 0.45$$
$$P_1 - P_2 = 1 \text{ in.}$$

$$\begin{aligned}
\text{Log } Q &= 1.301030 \\
\text{Log } Q^2 &= (2)(1.301030) = 2.602060 \\
\text{Log } L &= 1.698970 \\
\text{Log } \rho &= \bar{1}.653212 \\
\text{Log } Q^2L &\quad 3.954242 \\
\text{Log } 2310 &= 3.369216 \\
\text{Log } 2310^2 &= (2)(3.369216) = 6.738432 \\
\text{Log } (P_1 - P_2) &= 0.000000
\end{aligned}$$

[1] From Danforth's Mech. Process, p. 334.
[2] Gerhard, American Practice of Gas Lighting.

$$\text{Log}\ \frac{Q^2 L \rho}{(2340)^2(P_1 - P_2)} = 7.215810 - 10$$

$$\text{Log}\ \sqrt[5]{\frac{Q^2 L \rho}{(2340)^2(P_1 - P_2)}} = 1.443162 - 2 = \text{Log}\ d.$$

$$d = 0.278 \text{ in.}$$

A computer based on this formula has been designed by William Cox. The use of this computer saves much time in determining the requisite size of pipe. The sizes of pipes specified in the computer are somewhat larger than the calculated values from Pole's formula.

The following short table may be used for approximate calculations. This table gives the diameter of pipes in decimals of an inch. It is based on a table originally published by Clegg.[1] The table has been abbreviated by omitting the two last decimal places.

Table Showing the Diameter of Pipes, in Decimals of an Inch, to Supply Outlets at Certain Distances from the Main

Dist. of outlets from main in feet	Number of burners each consuming 5 cu. ft. per hr. under a pressure of 1 in. (water)												
	3	5	10	15	20	25	30	40	50	100	150	200	300
	Diameter of pipes, in decimlas of an inch												
5	0.155	0.189	0.249	0.291	0.329	0.359	0.388	0.431	0.474	0.626	0.739	0.826	0.975
10	0.177	0.217	0.286	0.337	0.378	0.413	0.444	0.498	0.515	0.719	0.838	0.919	1.116
15	0.192	0.235	0.310	0.365	0.410	0.448	0.482	0.540	0.591	0.780	0.917	0.129	1.210
20	0.203	0.249	0.329	0.387	0.434	0.471	0.510	0.572	0.626	0.826	0.971	1.090	1.281
30	0.220	0.270	0.356	0.419	0.470	0.514	0.553	0.621	0.679	0.895	1.053	1.182	1.390
40	0.233	0.286	0.378	0.444	0.498	0.545	0.586	0.658	0.719	0.948	1.116	1.252	1.472
50	0.244	0.299	0.395	0.464	0.521	0.570	0.613	0.688	0.752	0.992	1.167	1.309	1.539
60	0.253	0.310	0.410	0.482	0.540	0.591	0.636	0.713	0.779	1.029	1.210	1.357	1.597
70	0.261	0.320	0.422	0.497	0.557	0.609	0.655	0.735	0.804	1.061	1.248	1.310	1.646
80	0.268	0.329	0.434	0.513	0.572	0.626	0.670	0.755	0.826	1.090	1.287	1.438	1.691
90	0.274	0.337	0.444	0.522	0.586	0.641	0.689	0.773	0.846	1.116	1.312	1.472	1.731
100	0.280	0.344	0.454	0.533	0.599	0.654	0.704	0.790	0.864	1.139	1.340	1.503	1.768
150	0.304	0.373	0.492	0.571	0.649	0.710	0.763	0.856	0.937	1.236	1.453	1.630	1.918
200	0.322	0.395	0.521	0.613	0.688	0.752	0.809	0.907	0.992	1.309	1.539	1.727	2.031
250	0.337	0.413	0.545	0.641	0.719	0.786	0.846	0.919	1.037	1.369	1.610	1.806	2.124
300	0.349	0.428	0.565	0.665	0.746	0.815	0.877	0.981	1.076	1.420	1.669	1.873	2.254

The next step in designing a system of piping, after the consumption or size of the various outlets and the best direction to run pipes have been determined, is to determine the proper size of pipes to install. This is best accomplished by beginning at the outlet most remote from the meter and working towards it. When the first branch line is reached, the proper size is again determined by starting at the far end of the branch and proceeding to the junction where the quantities of gas for the two pipes are added and the same process is repeated until finally the meter is reached.[2]

6. Installing Gas Pipe.—In installing pipe for gas service a few simple precautions should be kept in mind. Many cities have local regulations to which the installations must conform. Some require that all pipes and fittings which are to be covered with concrete or cinders must first be covered with tarred paper. When changing the direction of the run, the pipe must not be bent for this may cause a split of the seam. Fittings should always be used whenever a change in the direction is necessary. The pipes should be supported by hangers or supports 10 ft. apart, approximately. When the horizontal runs are to be covered by a floor, the pipes

[1] Gerhard, American Practice of Gas Lighting, p. 46.

[2] H. R. Sterrett, Piping Houses for Gas Lignting, Trans. of Illum. Eng. Soc., vol. 10, p. 298.

may be placed in notches on top of the joists, Fig. 3. Care should be taken to avoid sags in the pipes for moisture and condensation will collect in these preventing the free flow of gas. The horizontal portions should all be sloped either towards the outlet or the meter so that pipes may be readily drained.

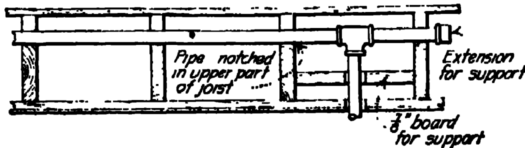


FIG. 3.—Ceiling outlet.

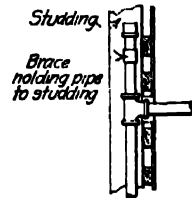


FIG. 4.—Wall outlet.

Fixture connections extending through the walls or ceiling should have extra supports, and the measurements should be exact allowing the fixture to screw up tight and flush with the wall or ceiling. Fixture connections are shown in Figs. 3 and 4.

Every outlet in the entire gas system must have a valve. A valve is also placed on the street side as well as the house side of the gas meter, Fig 5. All large mains and branches must be provided with valves. These valves are invariably of the plug type.

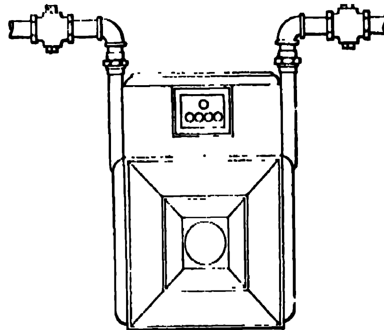


FIG. 5.

7. Testing.—After all pipe is installed in the building and before any plastering or finished flooring is done, the entire system of pipe is subjected to an air test of about 10-lb. gage pressure. All outlets are capped or plugged except one and that one is fitted with the necessary pump and gage. After the air is pumped in to the required pressure, any leak in the system will be noted by the lowering of the gage. Leaks are located by the use of soap suds, and also by forcing ether into piping system. Any defective parts which are disclosed by the test should be taken out and new material put in place.

There are many appliances on the market which use gas as a fuel. The installation of most of these is a comparatively simple process. In the case of cooking appliances, such as, hot plates, the smaller ranges, broilers, bake ovens, etc., the only consideration is the correct sized pipe. Some heating apparatus consuming considerable quantities of gas must be provided with a flue to permit the escape of the burned gases.

SECTION 10

ELEVATORS

By E. Hollander

The purpose of this chapter is briefly to describe modern elevator equipment, including dumb-waiters, escalators, inclined elevators, spiral gravity conveyors, and chutes.

In planning a building it is very important to make a careful study of the requirements of elevator service, as the commercial success of a building, in a large measure, is entirely dependent upon the kind of elevator service obtained. It is therefore essential that suitable provision be made in the planning for the installation of elevators to meet fully the demands of the building. High cost of land necessitates the erection of tall buildings, which in itself presents a very serious problem to architects and owners, as it is necessary to make the upper floors readily accessible in order to be attractive. The building must have a maximum percentage of rentable floor area to make it profitable. This makes it necessary to install elevators best suitable for the transportation requirements, in order that a minimum number will be required.

The first cost of an individual elevator of the most suitable type and control may be considerably higher than an individual elevator of a type not so suitable, but when it is borne in mind that fewer elevators will be required, the saving in cost of fewer hatchways with enclosures and appurtenances, wages of operators, and cost of electric power, together with increase in rentals obtained by greater rentable floor space, warrants the installation of the best type of equipment, even without giving credit to its superior operation and control.

The problem of vertical transportation of freight elevators is also one that must be carefully considered. The number of elevators, size and shape of car, location of same in relation to the horizontal lanes of traffic, size and location of openings, type of hatchway enclosure doors and their method of operation, and load, speed, and type of control of elevators constitute a very important problem which must be carefully analyzed for each individual installation.

Where an elevator with a duty of 2500 lb. at 50 ft. per min. speed, with a platform size of 6 × 6 would be satisfactory for a freight elevator of one or two stories travel for a small building in an outlying district, used for very intermittent service, or where an elevator of 4000 lb. at 100 ft. speed with a platform size of 8 × 10 would be satisfactory for a similar size of building requiring heavier capacity, in large, modern manufacturing plants, operating under high production and warehouses in which a considerable amount of freight is handled, high-speed elevators are installed with speeds up to 450 ft. per minute and with loads up to 10,000 lb. or 12,000 lb. capacity, with platform sizes varying from 10 × 12 to about 12 × 24 ft., depending upon the kind of freight to be handled, and of a type that makes accurate stops at floor landings without "inching" or "jockeying."

During the past few years, a remarkable advance has been made in the art of elevator design and construction. Hydraulic elevators, with the exception of the occasional installation of the plunger sidewalk type, are practically no longer manufactured or installed; they have given way entirely to the electric elevator. Fig. 1 shows an electric sidewalk installation.

The geared, drum-type electric elevator machines, that were heretofore installed for freight elevators, service elevators, and medium-speed passenger elevators, have also been practically entirely superseded by the geared single-wrap traction elevator machines.

The simplicity in design of the single-wrap traction machine, its adaptability to various conditions of layout, the development of sheave grooving that will positively maintain continued, constant traction and long life of both sheave and ropes, and the inherent safety characteristics of all traction machines of minimizing the possibility of the car or counterweight's being drawn into the overhead work, which was possible with the overwinding of drum machines, caused its adaptation.

1. Electric Elevators.—Electric elevators are primarily divided into two classes—geared single-wrap traction elevators for slow- and medium-speed service; and gearless traction elevators for high car speeds and where intensive service is required.

The geared single-wrap traction machine employs a worm-gear reduction between the motor and traction driving sheave, permitting the use of a moderate-speed motor. The traction driving sheave, around which pass the hoisting ropes, is provided with grooves of special design to maintain continual, constant traction and long life to

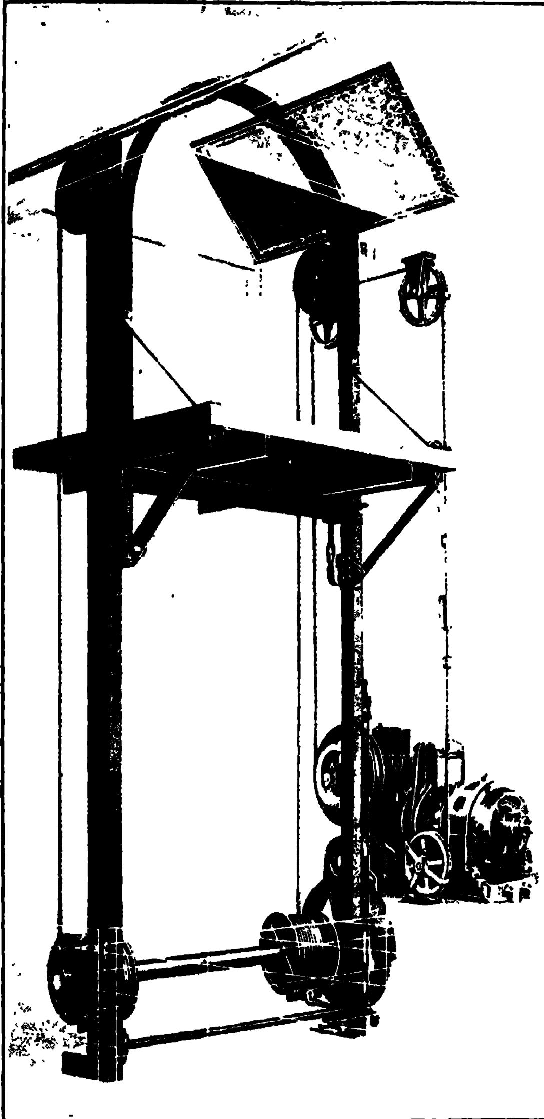


Fig. 1.—Double drum type electric sidewalk elevator.

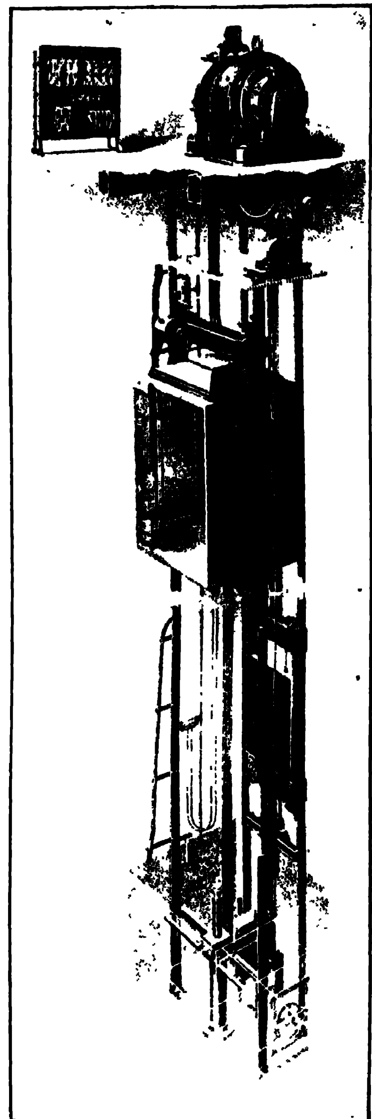


Fig. 2.—Gearless traction passenger elevator.

sheave and ropes and is driven directly from the worm gear through a spider, which is mounted on a heavy steel shaft and is securely bolted to both the worm gear and sheave.

The gearless traction machine, as its name implies, does not employ a gear reduction between the motor and traction driving sheave. The sheave is mounted directly on and bolted to the armature shaft of an extremely slow-speed motor, resulting in a machine of very high efficiency. Fig. 2 shows a gearless traction installation.

As previously stated, drum machines are practically no longer manufactured, but in view of the numerous existing installations, a layout is shown.

2. Location of Machine.—Electric elevator machines are usually located directly over the top of the elevator hatchway. For installations such as residences and hospitals or where the construction of the hatchway is such that it will readily transmit sound or possible vibration, or where the slightest noise is objectionable, it is advisable to locate the machine in the basement.

An overhead installation has the following advantages: Better rope leads are usually obtained; also, shorter length of ropes with consequent lesser cost of renewals; it eliminates the necessity of providing space for a machine room in the basement; it affords a ventilated and lighted machine room with minimum additional cost of providing the usual penthouse to cover overhead sheaves; and it generally reduces the overhead loads on the supports.

Sound isolation is occasionally resorted to in cases with geared overhead alternating-current installations, as shown in Fig. 3.

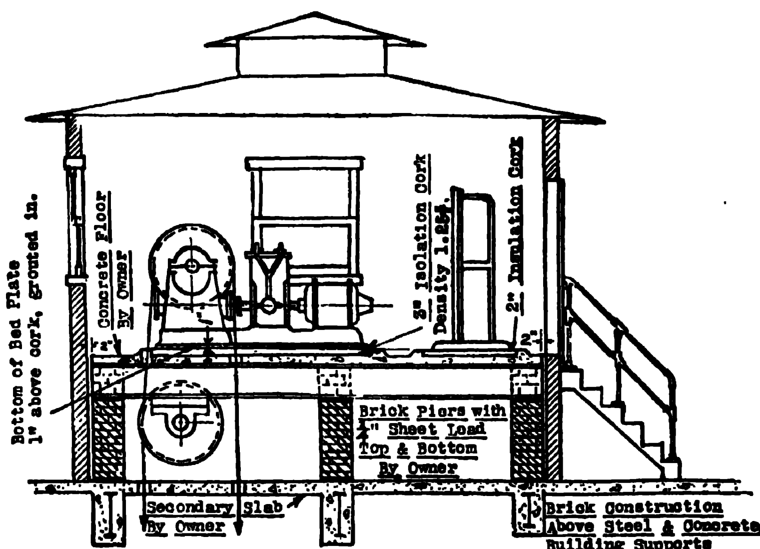


FIG. 3 A method of sound insulation for overhead installation.

3. Counterbalancing.—Electric traction elevators are overbalanced by means of a counterweight which is equal to the entire weight of the car hanging on the ropes plus the average load, which is usually about 40% of the maximum load. This results in an economic drive, as the elevator, during the greater part of the time, carries only average loads. When the load in the car is equal to the overbalance, the motor is required only to overcome friction loads; when raising maximum loads, the motor must develop enough power to raise the difference between the maximum load and the overbalance-plus frictions; when lowering maximum loads, electric power is usually regenerated and forced back into the line.

The counterweight of a single-wrap traction machine is secured by a number of steel ropes, which, for an overhead installation, run up to the top of the hatchway and over the traction driving sheaves and thence down to the top of the steel safety car frame, the ropes being secured to the counterweight and car frame by means of special hitches.

With gearless traction machines, the roping is similar, except that two half wraps of the ropes over the traction driving sheave are obtained by the use of a secondary sheave (see Fig. 4, General Arrangement of Roping for 1:1 Gearless Traction Installation, and Fig. 5, General Arrangement of Roping for 2:1 Gearless Traction Installation).

4. Layout.—With a single-wrap traction machine located overhead, it is always advisable to proportion the car of such shape that the traction driving sheave will span the center of the car and counterweight, thereby eliminating the use of a deflector sheave. By this means, a 180-deg. arc of contact will be obtained between the ropes and traction driving sheave. Gearless traction machines are double wrap; this requires a secondary sheave which also serves as a deflector. The relation of the arc of contact and the weight of the empty and fully loaded car

must be of an amount to obtain definite traction for either of these machines. For this reason it is necessary not only to lay out a car of economic shape, so that passengers may readily enter the car or leave it but also to locate the counterweight in relation to the center of the car, so as to obtain the proper arc of contact.

With large freight elevators, where it is impossible for the driving sheave to span the center of the car and counterweight, and an inadequate arc of contact is obtained with the use of a deflector sheave, it is usual practice to rope the elevator 2 : 1 by providing two sheaves in the car crosshead so spaced that the driving sheave spans from one of these sheaves to the sheave on the counterweight, thereby obtaining 180 deg. arc of contact on the driving sheave (see Fig. 19 showing the layout of garage elevator).

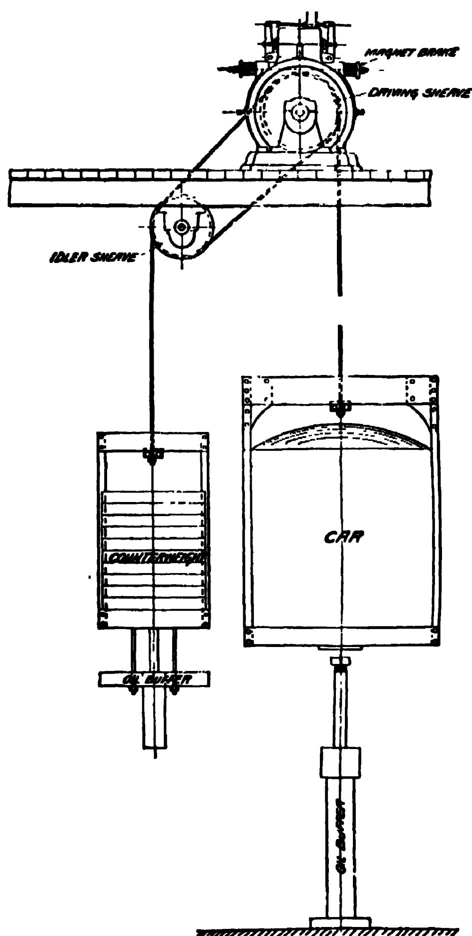


Fig. 4.—General arrangement of roping for a 1 : 1 gearless traction installation.

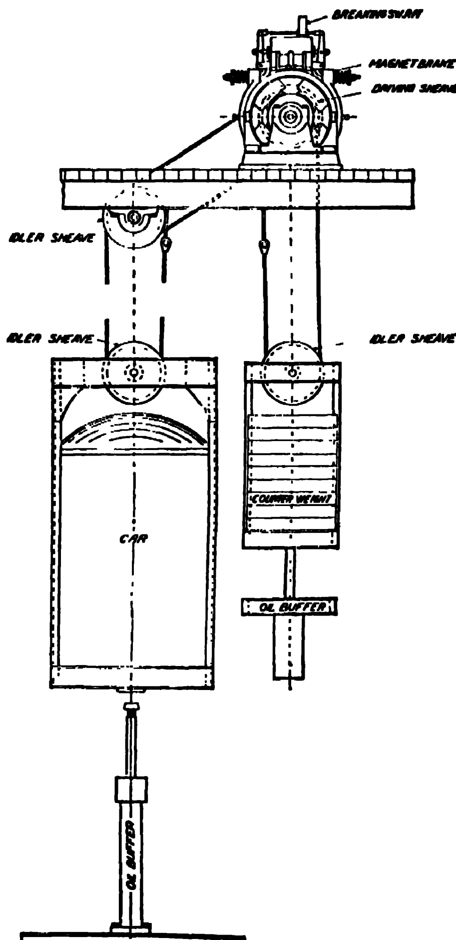


Fig. 5.—General arrangement of roping for a 2 : 1 gearless traction installation.

5. Capacity and Loading of Passenger Elevators.—The rated load of a passenger elevator in pounds shall not be less than the amount in Fig. 6, corresponding to the effective inside area of the car.

The codes in various cities specify that the loads shall not be less than 75 lb. per sq. ft. This is based on the assumption that an average person occupies a 2-sq. ft. area and weighs 150 lb. It has been found, in actual practice, that passenger cars for department stores, roof gardens, and subway stations are loaded 100 to 120 lb. per sq. ft. effective area.

6. Rope Compensation.—With high-rise, single-wrap traction elevators, the varying weight of the ropes is compensated by means of chains suspended from the bottom of the car and counterweight. These chains are often interwoven with sash cord in order to minimize the noise. With gearless traction elevators, ropes are usually installed in preference to chains, due to their quiet operation, especially in the case of high-speed installations. The use of ropes generally requires a pit of greater depth in order to provide space for compensating sheave-and-tension weight.

7. Clearances.—It is necessary to provide proper runby clearance above the extreme top of the car safety frame to the underside of the machine-supporting beams. When a deflector or secondary sheave is used, it is general practice to provide a metal grating or concrete slab below this sheave across the entire hatchway, in which case the clearance should be to the underside of the grating or slab. It is also necessary to provide proper pit depth below bottom

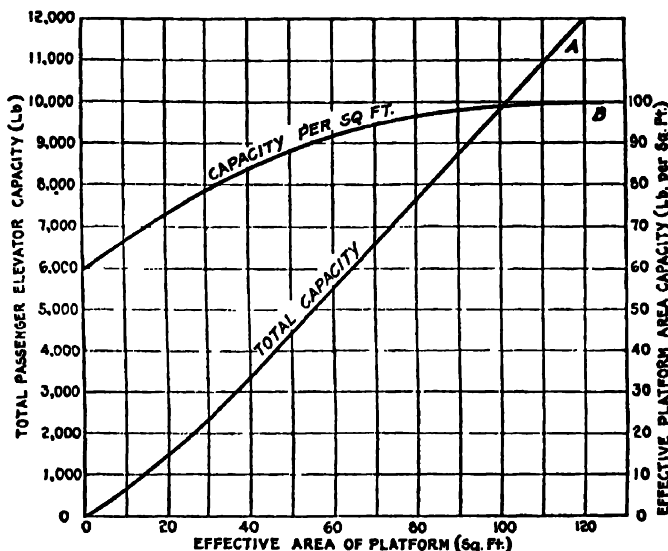


FIG. 6. Plot showing passenger elevator carrying capacity corresponding to effective platform area.

NOTE: For passenger elevators having effective platform areas above 120 sq. ft., the rated capacity shall not be less than 100 lb. per sq. ft.

landing. The clearances shown on layouts in this article are made to cover the general practice. It should be noted, however, that in many states and cities, these clearances are governed by ordinances and also by the American Engineering Standards Safety Code for elevators and should be checked so as to comply with same.

8. Safeties.—Electric elevators are provided with various electrical and mechanical safety devices, such as hatchway limit and stopping switches for automatically slowing down and stopping the car as it reaches the terminal landings; and safety emergency switch in the car, so that it can be stopped at any point in the hatchway. Safeties are installed on counterweights which, for unavoidable reasons, run above rooms or passageways.

There are two types of car safeties—instantaneous and gradual stop. The instantaneous is of the roll type and is used with slow-speed elevators and should not be installed where the speed of the car is more than 150 ft. per min. The use of this type of safety is restricted by the codes of various cities to car speeds of not over 150 ft. per min.

There are several types of gradually applied safeties, the one most commonly used being the wedge-clamp type used with moderate- as well as high-speed elevators, as shown on Fig. 7, together with Fig. 8, illustrating the safety governor.

The governor is provided with electrical switches to slow down the motor in case the elevator exceeds normal speed, due to high voltage or excessive load, and finally causes the machine to be stopped; but, should the elevator

for any reason continue to increase in speed, the operation of the governor will cause all power to be cut off from the motor, the brake to be applied, and the machine to stop. In case of emergency, due to parting of the ropes, the action of the governor will cause heavy steel safety jaws, mounted in the safety frame under the car, by degrees to grip the guide rails and bring the car to a smooth and gradual stop. Steel swivel gibs are inserted in the jaws to obtain parallel alignment with the faces of the guide rails. The gripping of the governor rope causes the drum, which is mounted in the safety frame under the car, to revolve. This, in turn, operates right- and left-hand screws, forces wedges between the rollers of the guide clamps, and causes the heavy steel jaws gradually to grip the guide rails.

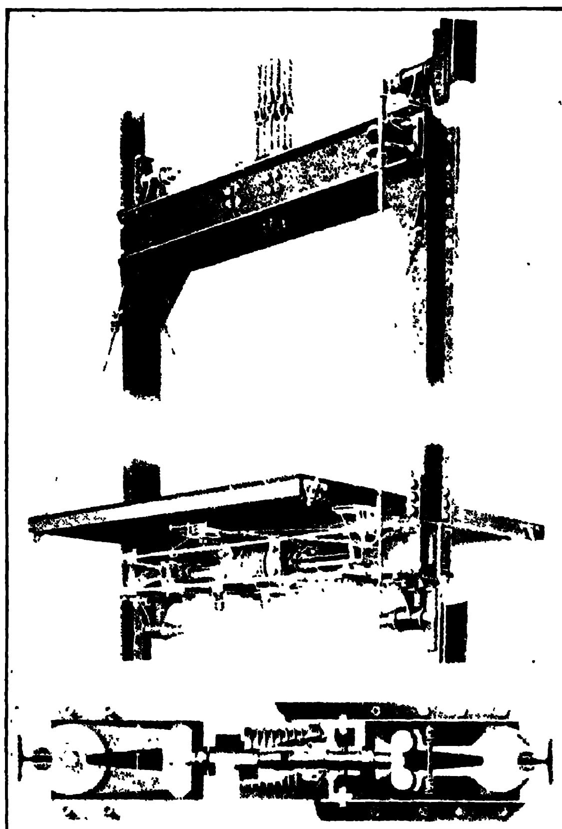


Fig. 7. Wedge clamp type of safety.

Another type of gradually applied safety is the flexible guide-clamp type. This type of safety may be used for moderate- as well as high-speed elevators, and the advantage over the wedge-clamp type is that it is quicker and more positive in action, without being too abrupt for safety regardless of the initial car speed.

Another, or special type of safety, known as the retarder type and consisting of a number of steel wires and retarders, is sometimes installed at the top of the hatchway, for very high rise, fast-speed elevators, and is used in conjunction with the regular gradually applied safety, serving as a "top stop and snap over," so that should the car for any reason run by the terminal landings, the action of the retarders will hold these members and prevent them from running into the overhead work.

9. Oil Buffers.—Oil buffers are installed with all gearless traction elevators and with geared single-wrap traction elevators of about 300 ft. speed and over. This requirement should, however, be checked with the code of the municipality in which the installation is to be made. Two of these buffers are provided for each elevator; one is located in the pit under the car, and the other hung to the bottom of the counterweight. These buffers are designed to bring the car and counterweight to a gradual and positive stop by absorbing the energy of the moving

parts when travelling at the tripping speed of the governor. The buffer consists of a piston, which, in its movement, forces oil through carefully calculated, graduated openings from one chamber into another, thus offering a predetermined resistance to motion (Fig. 9).

10. Micro Leveling.—The difficulty of cars making accurate landings has long been a stumbling block and not until the advent of the micro-drive or self-leveling elevator was this feature automatically accomplished. With micro-leveling elevators, accurate stops are automatically made by the car itself, and maintained at the floor landings regardless of stretch of ropes, or load in the car, or speed.

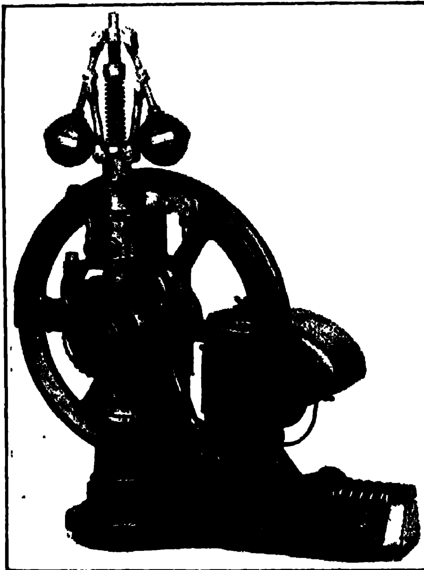


Fig. 8.—Safety governor with switch.

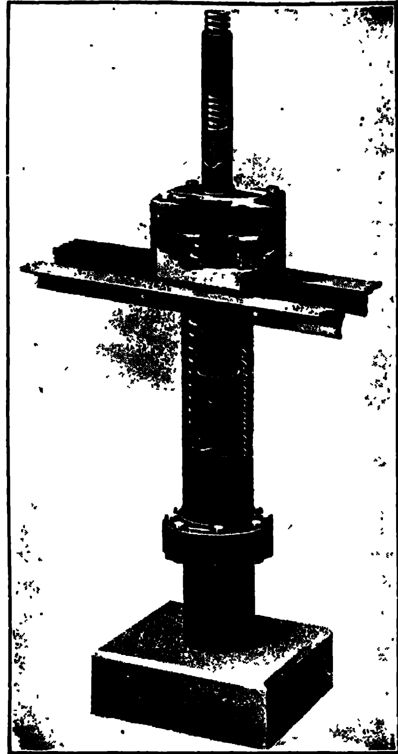


Fig. 9. –Otis patented spring return oil buffer.

The importance of the microleveling elevator is readily seen, as it eliminates the tripping hazard at the landing and results in an elevator of long life with minimum upkeep; saves considerable time in the round trip of the elevator, and also reduces the power consumption.

The microleveling elevator is very essential for installations in hospitals, where it is necessary to carry invalids on stretchers or wheel chairs; freight elevators, on which loads are carried on small wheel trucks; and passenger elevators, where the automatic making of accurate stops is essential to quality and quantity of service.

Microleveling may be accomplished by means of a machine that is provided with an auxiliary microdrive or by means of leveling through the main motor.

11. Operation.—Hand rope and other forms of mechanical control formerly used with slow-speed elevators are rapidly being replaced by car-switch magnet control and also by double-button control—car-switch control is more flexible and easier to operate.

Double-button control is very advantageous and used with slow-speed freight elevators where the installation does not warrant an operator. With this control, the car is called to the floor by the constant pressure of an up or down hall button and sent to a floor by the constant pressure of an up or down button in the car. The hatchway openings are protected by means of manually operated doors or gates which are equipped with mechanical locks and electric contacts, designed to prevent the operation of the car when any of the gates are open and to prevent the hatchway doors or gates from being opened, except when the car is at that floor.

Moderate- and high-speed elevators are all provided with full magnet control, employing a switch in the car, or push buttons in the car or at the landings for automatic operation—the trend being automatic operation in various

forms, such as regular automatic elevator for residences and small apartments, collective automatic control for apartments and hotels where the service is more intensive, department-store control, and signal control for high-speed intensive service in office buildings.

12. Control.—There are two types of control now in use—the *rheostatic* or *resistance control* and the *unit-multivoltage control.*

The rheostatic type of control includes all controllers employing resistance for the purpose of controlling the elevator motor during the acceleration and retardation periods. With rheostatic control it is impossible to obtain the highest rates of acceleration and retardation because these vary with varying loads. This type of control is not so efficient as unit multivoltage control and is wasteful in power consumption caused by the current's passing through resistances. Rheostatic control is now used practically only with slow- and moderate-speed elevators; whereas, unit-multivoltage control is used for the highest class of operation and also where intensive service is required.

Unit-multivoltage control employs an individual motor-generator set for each elevator, for providing variable or graduated voltage to the elevator motor. Automatic acceleration and retardation is obtained magnetically and independently of the operator or load in the car, resulting in practically constant time acceleration and retardation. With this control, the highest rates of acceleration and retardation are obtained and without discomfort to the passengers, eliminating the "sinking spell" so common with other types of control. Its use is very essential where the highest quality of operation is desired and where intensive service is required. With this control, no current is passed through resistances, as with rheostatic control, resulting in economic operation. Further economy is obtained by applying graduated voltage to the brake and control magnets. Unit-multivoltage control has a further advantage in that it can be equally applied to alternating-current as well as direct-current supply, the driving motor of the generator set being wound to suit the characteristics of the power supply, the generator always being of the direct-current, multipolar type.

Heretofore, where only alternating-current power supply was available, it was necessary to provide either a straight alternating-current elevator machine, which is restricted in speed and also very wasteful in power, or a direct-current elevator machine, receiving constant voltage supply from an alternating-current-direct-current motor generator. In either case, rheostatic type of control was provided, which limited the quality of operation and service obtained.

A unit-multivoltage gearless traction installation is shown in Fig. 10.

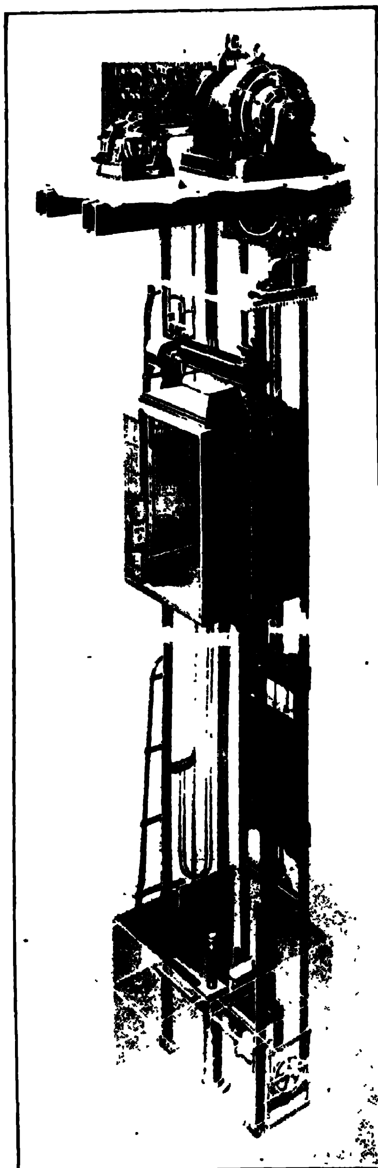


Fig. 10.—Gearless traction unit multi-voltage control passenger elevator installation.

13. Automatic Push-button Elevator.—Prior to the advent of microleveling, the automatic push-button elevator was limited to very moderate speeds, owing to the difficulty of making stops with any degree of accuracy. With microleveling, materially increased car speeds are possible. This naturally opened up a very wide field in its application to various types of controls, so that we now have automatic elevators for residences, apartment houses, hotels, office buildings, and for heavy-duty freight service. The automatic elevator has its advantage in that it dispenses with the use of an operator.

With automatic push-button control, a single button is provided at each landing, and a full bank of buttons, including a stop button, in the car, corresponding to the various floors; car gate with electric contact and electric interlocks on each hatchway door; together with a retiring cam on the car. The pressing of a hall button will bring the car to the floor, provided it is not in use and all the hatchway doors are "closed and locked" and the car gate

closed. The passenger, on entering the car, is required to close the hatchway door and car gate before pressing the button in the car corresponding to the floor desired. On pressing the button, the car automatically proceeds to and stops at the desired floor. No one can call the car from the hall until after the car has stopped at the floor and the car gate has been opened and closed.

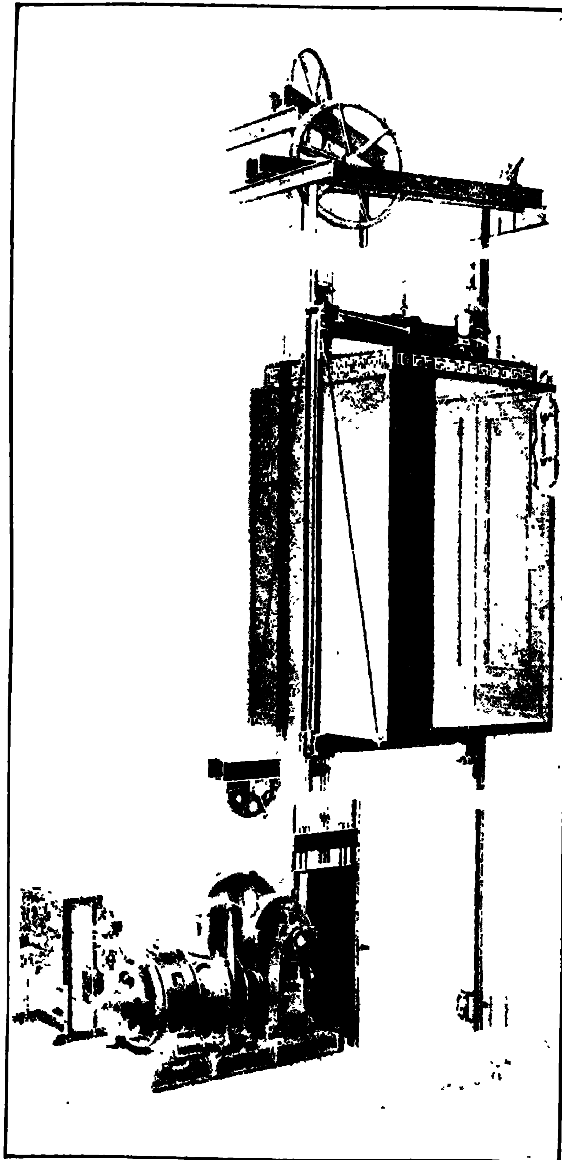


FIG. 11.—Geared single wrap traction push button elevator.

The retiring cam on the car is either motor or magnet operated and serves to lock and unlock the door at which the car is standing and prevents a hatchway door from being unlocked as the car passes the floor. It is the "master key" for all hatchway doors. Reliable interlocks should be provided on all hatchway doors and an electric contact on the car gate. The electri ... ch door lock should be made integral with the locking member, so that

the door will be not only closed but also locked before the car can be operated. Fig. 11 is a geared single-wrap traction push-button installation.

14. Dual Control.—When the service requires an operator only part of the time, an operating switch is provided in the car in addition to the push buttons, in which case, by means of a throw-over switch, the push buttons in the hall are connected electrically to an annunciator in the car. This is known as dual control.

15. Special Automatic Control.—A special form of push-button control has been developed for freight and warehouse work, where the service will be limited to stopping, on any given trip, at only one floor besides the starting floor.

With this control, dispatching buttons corresponding to each floor for each elevator are located on the main floor, preferably set into a table, at which a dispatcher sits within full view of all elevators. As a car is loaded, the dispatcher, by touching the proper button, sends it to the floor destination, either with or without any person accompanying it. When that floor is reached, the car stops automatically, and an automatic hoistway door-operating machine raises the door, which is of the vertical type When the trucks are run off by the attendant at that floor, and any other trucks which may be ready have been run on, the attendant touches a door release button, which permits the door to close, at a safe speed, by gravity. When the door is closed, touching a second button dispatches the car to the main floor, where, upon the door's being opened, the cycle may be again started. The same gate machine operates all the doors on the same side of a given elevator, a selective device, which operates through the floor controller, and separate clutch connections for each door, permitting it to open only one door at a time, and that the door of destination.

16. Collective Automatic Control.—For installations where automatic operation is advantageous but where the height of the building or the "traffic demands" are such that the regular automatic control just described is inadequate, owing to the fact that when a car is being sent or called to a floor it passes other floors for which similar calls have been made, a new type of control was developed, known as collective automatic control, which, in combination with unit multivoltage, results in a control far in advance of that which heretofore was obtained. Very high car speeds are not possible with microleveling, thereby making automatic operation not only possible but also desirable for buildings where heretofore this type of equipment would not be used.

With collective automatic control, the car stops and collects all calls made at the various landings, when it is travelling in the direction for which an up or down hall button has been pressed, provided they have been pressed in ample advance of the car's reaching the landing. The car also stops at all floors for which car buttons have been pressed and in the order that these floors are reached, irrespective of the sequence in which the buttons have been pressed. Should the car be fully loaded on its descending trip, it will automatically pass floor landings for which calls have been made for this direction but on its next descending trip will collect such calls. It is necessary only to press an up or down hall button once; the car will always respond to the call.

After the car has answered all calls and discharged the last passenger, it will either remain at the floor where it last stopped or automatically return to a predetermined home station, as may be desired.

The motor generator is automatically started by the pressing of a hall button or upon a passenger's entering the car, and when it has attained full speed, the car will respond to the hall call or to the pressing of a car button. The motor generator will run continuously for a predetermined adjustable time after the elevator has completed its trip.

The elevator is provided with interlocks, retiring cam, car gate, and contact, similar to an automatic push-button elevator, and the standard equipment also includes manually operated door closers and a car platform of a design such that when there is no load in the car and the car gate is open, the car can be called by the pressing of any hall button. When there is a load in the car, however, the car gate must always be closed in order for the elevator to be operative. In either case, all hatchway doors must be closed and locked.

17. Collective Automatic Control for Intensive Service.— For installations where "traffic demands" require more than one elevator, it is advisable to locate these elevators in pairs, an arrangement which permits a very flexible arrangement of home stations: as, for example, in an apartment house, the morning traffic being in the down direction, the home stations of both cars should be at the top; in the early part of the evening, when the tenants are coming home, the home stations should be located at the entrance floor. The flexibility of this arrangement allows the use of one car when traffic is light and the calling into use of the second car automatically when traffic is heavy.

18. Signal Control.—The trend of the present times, with elevators as well as with other types of industrial equipment, is toward automatic operation, where important functions of operation are accomplished with precision and promptness and are not dependent upon the

mental and physical alertness or sluggishness of an attendant or operator. This condition brought about the development of automatic signal control for elevators and was made possible only by the use of microleveling in combination with unit multivoltage. Signal control is as fully automatic as it is possible to make an elevator control for intensive service.

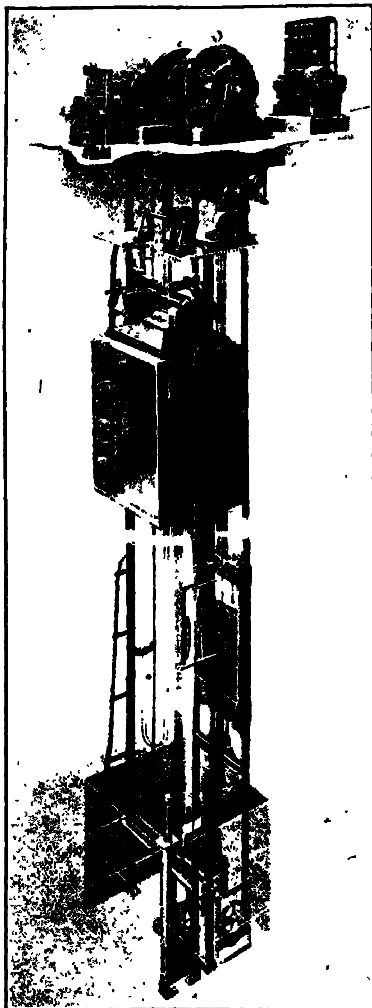


Fig. 12.—Single control gearless tractio micro-drive elevator.

As buildings increased in size, due to high land values, architects and owners were confronted with a very serious problem of making the building commercially successful by providing high-class elevator service without sacrificing too much rentable floor space. This has intensified the demand for automatic signal control, which may be used for any number of elevators. The name "signal control" is given because the waiting passengers at a landing actually cause the stopping of the car, instead of signalling the operator in the car to do so. All that the operator or attendant in the car is required to do is to press the car buttons and initiate the starting of the car—acting as a guard.

The passengers on entering the car advise the attendant of their desired destination, and regardless of the order in which he presses the buttons in the car, it will automatically stop in proper sequence at the floors for which buttons have been pressed, and the stops are made level with the floor landings.

At each intermediate floor landing there are two stopping buttons for all cars in a bank, one for the "up" direction and one for the "down" direction, except at the terminal floor landings, where only one button is necessary. There is also provided at each intermediate floor an up and a down signal lantern for each car, except at the terminal floors, where only a single lantern is necessary.

The car is stopped at a floor by the momentary pressing of a hall button by a waiting passenger at that floor or by the attendant in the car pressing the buttons in the car as called for by passengers as they enter the car.

When the attendant receives a signal from the dispatcher to start the car, he moves the small switch handle in the car-operating panel, which causes the power-operated car and hatchway doors to close. The instant these doors are closed, the car automatically starts and proceeds on its trip, and when it approaches the first landing for which a button has been pressed, either in the car or at that landing, it automatically slows down and stops level with the landing. The car and the hatchway doors open automatically while the car is leveling. After passengers leave or enter the car, the operator moves the small switch handle, causing the car and hatchway doors to close, and again the car starts and will automatically stop at all floors at which car or hall buttons have been pressed.

Should a car be behind in schedule or fully loaded, the operator, upon pressing the "non-stop" button in the car-operating panel, permits the car to pass the landing for which a hall button has been pressed. In this event, the signal remains registered, and the call is automatically transferred to the next car travelling in the desired direction, which will answer the call.

With signal control, when a waiting passenger presses a hall button, the nearest available car will always respond to the call, which is not always the case with the older method of signalling to the operator in the car, where the stopping is dependent upon his whims or his knowing that the signal has been given. As the car approaches the landing at which it is to stop, a hall signal lantern automatically illuminates, indicating to the waiting passenger which car will stop in response to his call. The signal light is automatically extinguished the instant the car leaves the landing.

When the car arrives at the terminal landing, its direction of travel is automatically reversed after stopping. A switch may be provided at the dispatcher's station automatically to reverse the travel of the car at a predetermined intermediate floor landing, should it be desired.

A switch is also provided at the dispatcher's station, so that where a car travels below the ground-floor landing, it may be automatically reversed at either the ground floor or the bottom terminal landing when desired.

A switch is provided in the car-operating panel by means of which the attendant in the car may reverse the direction of travel of the car at any floor without completing the full trip, should it be desired. If, for any reason, it is desired to operate the car at a reduced speed, especially in case the car is travelling ahead of schedule, the speed

of the car may be reduced by means of a "slow-speed" switch provided in the car-operating panel. A switch is provided in the car-operating panel by means of which the car may be operated at leveling- or microspeed when necessary.

The advantages of automatic signal control may be briefly summed up as follows:

Signal control is fully automatic; the attendant only presses the buttons in the car and moves the small switch handle to "initiate" the closing of the car gate and hatchway door—practically serving only as a guard.

Signal-control elevators are always dependable, always responding to the calls made by the momentary pressing of hall buttons by waiting passengers. The car always stops level with the landings—eliminating the tripping hazard.

With signal control, the hall lights for each hatchway door are an integral part of the system and always illuminate in correct advance of the stopping car. The older systems have separate signal mechanisms, requiring complicated devices in attempting to adjust and correct the inherent inaccuracies of the signals, and even with these devices, the signals very rarely function correctly.

With signal control, a waiting passenger presses a hall button but once—a car is always sure to stop at that floor. With the older systems, a waiting passenger has to press the hall button repeatedly in order to obtain the attention of the operator.

Automatic signal control provides the smoothest, most accurate and rapid transportation and will transport more passengers in a given time than any other kind or type of elevator; hence, a lesser number are required, leaving a greater amount of rental floor space in the building. Fig. 12 shows a signal control gearless traction micro-drive installation.

19. Department-store Control.—The application of automatic control in modified form is now applied to department-store elevators in what is known as department-store control. This type of control is used in combination with microleveling and unit multivoltage. The cars are provided with an operating switch with a safety handle, which, when released by the attendant will cause the car to stop at any point in the hatchway.

When the operating switch is moved to the "start" position, the car gate and hatchway door will automatically close, and when they are closed, the car will start and accelerate automatically. The closing of the car gate and hatchway door can be arrested at any point and reopened by moving the operating switch to the "open" position.

When the operating switch is moved from the start to the "off" position, the car will slow down automatically as it approaches the microleveling zone and automatically stop level with the floor. While the car is leveling in the microleveling zone, the car gate and hatchway door are opened automatically.

If, while the car is in motion, the operating switch is moved from the start to the close position, the car will stop level with the next floor, and the car gate and hatchway door will remain closed, unless the operating switch is then moved to the open position.

The car is started, without opening the car gate and hatchway door, by moving the car-operating switch fro the close to the start position.

Floors may be passed without stopping by holding the operating switch in the start position.

The car will slow down and stop automatically at the terminal landings, and the direction of travel will be reversed automatically.

The direction of travel may be reversed at any intermediate floor by means of the reversal switch in the car-operating panel.

The car may be operated at slow speed by means of the slow-speed switch in the car operating panel.

A microswitch is provided in the car-operating panel by means of which the car may be operated at microspeed independently of the main controller.

"Up-down" signal lanterns are provided over each landing door at the intermediate floors, and single lanterns at the terminal floors. These lanterns are illuminated a predetermined distance in advance of the arrival of the car and are extinguished automatically as the car leaves that floor.

20. Hatchway Construction.—Freight elevators having a travel of more than two floors above the main floor, and all passenger elevators, should be installed in fire-resisting hatchways, conforming to the requirements of local laws and ordinances.

All landing openings in a fire-resisting hatchway enclosure should be provided with fire-resisting doors, panels, or fronts which comply with local laws and ordinances.

Projections extending inward from the general surface of the hatchway enclosure, and which are opposite a car entrance, should be beveled on the underside or guarded with metal plates or by wood faced with metal of not less than No. 11 U. S. gage. The angle of such bevel or guard plates shall be not less than 75 deg. with the horizontal. If plates or guards are used, they should be smooth and permanently fastened to the hatchway enclosure

With microleveling elevators, where the projection extends inward from the general surface of the hatchway enclosure opposite a car entrance, there shall be provided a substantial metal vertical face of not less than No. 11 U. S. gage, made flush with the projection and extending downward a distance not less than the bottom of the microleveling zone and beveled at the lower edge at an angle not less than 75 deg. with the horizontal.

Recesses other than windows and landing openings in the general surface of the hatchway enclosure, which are opposite a car opening, shall be filled in flush with the general surface of the hatchway.

The hatchway enclosure adjacent to a landing opening should be of sufficient strength to support in true alignment the landing doors and gates with their operating mechanisms and interlocks. (Reference to Safety Code for Elevators approved by the American Engineering Standards Committee.)

20a. Hatchway Enclosure Doors for Passenger Elevators.—No automatic fire door, the function of which is dependent upon the action of heat, shall lock any landing opening in the hatchway enclosure of any passenger elevator, nor any exit leading from any hatchway landing door to the outside of the building. Landing openings in passenger-elevator hatchway enclosures shall be protected by sliding doors, combination sliding and swinging doors, or swinging doors. No hardware, except that required for interlocks, operators, indicators, and signal devices, shall project beyond the line of the landing threshold.

20b. Hatchway Doors and Gates for Freight Elevators.—Landing openings in freight-elevator hatchway enclosures should be equipped with doors or gates, set as nearly as is

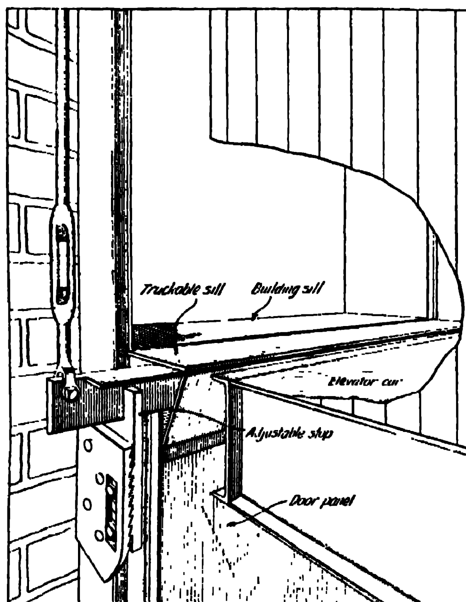


Fig. 13.—Shaftside view showing manner of supporting counterbalanced door in an open position.

practical flush with the hatchway. If doors are used, they should comply with the fire-resisting requirements for doors in such enclosures.

Landing openings in the outside walls for a building should be equipped with doors complying with the fire-resisting requirements for doors in such walls.

Hatchway gates, when made of grille, lattice, or other openwork, shall reject a ball 2 in. in diameter. Collapsible gates are not recommended but if used shall be so made as to prevent accidents due to shear.

Full automatic gates should be used only at terminal landings, with elevators operating at a speed not in excess of 75 ft. per min. Full automatic gates or doors should not be closed by the direct action of the car; their speed in closing may, however, be retarded by the car.

Semi-automatic gates or doors should be provided with a locking device which will prevent the normal opening of gates or doors unless the car is at or near the landing.

Gate or door counterweights should run in metal guides from which they cannot become dislodged or should be boxed in. The bottom of the guides or boxes should be so constructed as to retain the counterweight should the counterweight rope break.

The laws of most cities require that all freight-elevator shafts must be protected against accident and the spread of fire.

Counterbalanced doors of the iron-clad or corrugated-metal type are found very effective not only as a guard but also for fire protection. These doors may be manually or power operated, and when power operated, they may also be arranged to open automatically as the car approaches the landing at which it is to stop. They should be

provided with electric interlocks. In cases where a regular operator is not employed, it is advisable to provide the small vision panel in the doors so that the elevator car may be seen from the landing. Fig. 13 shows the shaft-side view of a counterbalanced door in the open position and of a type where the upper member of the lower half of the door serves as a truckable sill.

20c. Steel Guide Rails.—The use of steel guide rails is recommended for all elevators. Wood guides are practically no longer used, even for slow-speed freight elevators. Various elevator codes practically preclude the use of wood guides.

Steel guide rails are made in the following sizes:

Size, inches	Pounds per linear foot
3½ × 2⁷⁄₁₆ × ⅝	7.8
5 × 3½ × ⅝	15
5½ × 5 × 1¼	30

The weight of the guide rails should not be less than given in the following table:

WEIGHT PER LINEAR FOOT OF EACH STEEL GUIDE RAIL

Total weight of car and load / Total weight of counterweights — Per pair of rails: Above, pounds	To and including, pounds	Minimum weight of each car guide rail, pounds	Minimum weight of each counterweight guide rail, pounds: With guide-rail safeties	Without guide-rail safeties: 1:1 roping	Without guide-rail safeties: 2:1 roping
0	4,000	7½	7½	6½	6½
4,000	15,000	14	14	7½	7½
15,000	40,000	30	30	7½	14

Guide rails, particularly where in contact with the guide shoes when the car is at the landing, shall be securely fastened with iron or steel brackets (or their equivalent), of such strength, design, and spacing that the guide rails and their fastenings will be rigid.

Guide rails should be of such size and strength as readily to withstand the application of the safety when stopping a fully loaded car or the counterweight. The guiding surfaces of the rails upon which safeties operate shall be finished smooth, and the joints should be tongued and grooved. When the distance between the fastenings is excessive, backing should be used on the main rails. This backing is not necessary when the brackets can be fastened to substantial brick and concrete walls.

20d. Methods of Fastening. Brackets must be securely fastened to steel framing or masonry walls. Terra-cotta walls must not be used as a support for brackets.

Bond blocks and malleable-iron inserts should be used for fastening brackets to masonry walls whenever it is possible to have them set when the wall is erected. When neither bond blocks nor through bolts can be used, expansion shells can be used for fastening bracket bolts.

Holes for expansion shells must be drilled carefully to the correct diameter and in a solid portion of the wall. Holes carelessly drilled or located in a soft portion of the wall will cause an insecure fastening. Expansion bolts must not be used for fastening brackets of large freight or automobile elevators when they can be fastened by bond blocks or through bolts.

When main rails are erected back to back, with steel separator beams between them, intermediate rail clamps are used, if the distance between the brackets is excessive.

20e. Interlocks.—It is very important to note the necessity of providing adequate interlocks with all passenger elevators, as it has been proved by statistics that nearly all accidents occur at the hatchway doors. This provision is now so far reaching that it is practically universally required by codes.

The essential characteristic of interlocks is that the hatchway doors must not only be closed but also locked in order for the elevator to be operated, except that with microleveling elevators when the car is in the microzone and leveling toward the floor, the door may be opened at that landing.

20f. Door Closers and Accessories.- Modern elevator equipment also includes signal lanterns, position indicators, annunciators, starter's call back, mileage recorders, automatic guide lubricators, and door closers for hatchway doors.

These closers are either manually or power operated, assure the positive closing of the doors, and also prevent slamming. It is necessary to provide adequate space and supports for these devices. The layouts shown in this article do not show special provisions for the door closers.

21. Automatic Dumb-waiters.—Automatic dumb-waiters are practically miniature elevators, with control and safety features designed for this class of service. Their use covers a very wide field of application, and they are installed in buildings such as hotels, hospitals, restaurants, clubs, libraries, commercial buildings, etc.

A dumb-waiter installation consists essentially of hoist machine, floor controller, main controller, car and guide rails, counterweight, door locks and contacts, and doors.

The duties depend upon the class of service and height of travel. The loads vary from 50 to 500 lb., and the speeds from 50 to 400 ft. per min.

21*a*. Control Systems.—There are several types of control systems furnished, the proper type to be selected for a given installation depending upon the service requirements. The systems are as follows:

1. Multibutton control.
2. Limited multibutton control.
3. Call and return control.
4. Central-station group control.

Multibutton Control.—At each floor there is provided a push-button box containing a bank of buttons. The buttons are numbered to correspond to the floors served by the car. One button at each floor will be the call button. For example, at the fourth floor the call button will be No. 4, and at the fifth floor No. 5, etc. It is thus understood that there will be one call button in each bank, the others being send buttons. When the car is at rest and the door closed, it may be called to any floor by pressing the call button. All buttons are inoperative while the car is in motion and for a few seconds after the car stops, to allow time to open the door, also while the door is open.

When the car stops at a floor, a pilot light carried by the car gives notice of its arrival, and the door, being electrically unlocked, may be opened. When the door is again closed, the attendant at the floor may send the car to any other floor, and the car may also be called to any other floor by means of the call button. The send buttons are inoperative at all floors except when the car is at rest.

Limited Multibutton Control.—This system provides a full bank of buttons at one floor only. At the other floors there are furnished a call button and one or more send buttons, as required by the service. The operation otherwise is identical to the multibutton. Usually, one call button and one send button at the other floors will answer the requirements.

Call and Return Control.—At one floor there is provided a bank of push buttons corresponding to all floors served by the car. This, the home station, may be at the bottom floor or any other floor desired. On each of the other floors there is a call button.

If the doors are closed and the car is not in use, it may be called to any floor by pressing a call button.

All buttons are inoperative while the car is in motion and for a few seconds after it stops to permit the door to be opened, also while the door is open.

When the door is closed, the car will automatically return to its home station.

With this arrangement the car may be sent to any floor from the home station by pressing any one of the send buttons, and it will automatically return after a time interval has elapsed, if the door has not been opened. If the door is opened, the car will remain at the floor indefinitely. Upon closing the door, it will automatically return to the home station.

Central-station Group Control.—This type of control is recommended where two or more dumb-waiters are to be controlled by a single operator or dispatcher stationed on one floor—the bottom floor, for instance—or it may be used for a single car.

At each of the floors, except the home station, there is provided a single buzzer and a single call button. At the home station, where the operator or dispatcher is in charge, there is provided a multijack operating box for each car, a bank of push buttons, and a call annunciator. When one of these jacks is plugged, the car will automatically go to that floor. If the plug is removed while the car is in motion, the car will stop.

Each operating box has a signal lamp which gives three signals:

Bright, car running.
Dim, car stopped.
Extinguished, door open.

With this arrangement, the operator or dispatcher is aware of the conditions from the signal lamp, while the position of the car is indicated by the plug.

The bank of push buttons at the home station is connected to the floor buzzers, to signal to the floor attendants that the car has arrived at the floor or that the door should be closed. The pressing of the call buttons at the floors register calls in the annunciator at the home station With this system, the floor attendants may signal for a car,

open and close the doors, and load and unload the cars; otherwise, the entire control is handled by the operator or dispatcher at the home station.

Dumb-waiter machines should preferably be located at the top of the hatchway, although they may be located at the bottom of the hatchway, if necessary.

The dumb-waiter car should be made of sheet steel, preferably spot welded and riveted, and should be reinforced with an angle-iron frame. The cars are usually provided with one or more removable shelves.

The interior of the car should be illuminated with an electric lamp, so that the car may be seen through the vision panel of the door when it arrives at the floor.

One set of steel guide rails is provided for both the car and counterweight, the cold-rolled steel-beam section being preferable for this use. The rails should be joined together by fish plates and securely fastened to the hatchway construction.

Two types of door locks are furnished: (1) a mechanical lock in conjunction with an electric door contact, which should be used only for two-stop dumb-waiters and where code requirements permit its use. This combination of mechanical lock and electric contact prevents the door from being opened except when the car is at the floor and also prevents the operation of the dumb-waiter when any of these doors are opening; (2) the other type is a combination electromechanical interlock. The electric contact is interlocked with the locking member so that the contact is closed only when the door is closed and locked.

21b. Doors.—There are three types of doors that may be used—namely, standard vertical-sliding, vertical-sliding biparting doors (Peelle type), and swing doors.

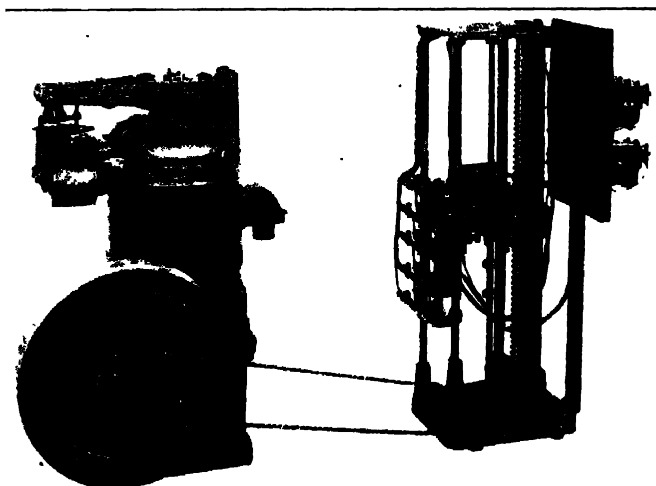


Fig. 11.—Dumbwaiter machine and floor controller.

The Peelle door has the advantage of requiring half the movement to provide a full opening. The swing door is not often used, as with this type of door it is difficult to attach the locks, etc. The doors should provide a clear opening 42 in. high, the inside height of the car, and should be provided with a small vision pane of wired glass 6 or 8 in. square or round, in order that the car may be seen when it arrives. It is important that the door bucks on all the various floors be in perfect vertical alignment. Fig. 11 shows dumb-waiter machine and floor controller.

22. Escalators.—The escalator is virtually a moving stairway and owes its success to its continuity of motion, its great capacity, and the small amount of current consumed for each passenger carried. It is always ready to receive passengers, there is no time lost in loading, starting, stopping, and unloading; consequently, it has great carrying capacity, which varies, depending upon the width between the moving hand rails.

The escalator consists essentially of the following parts:

1. The running gear, or moving steps, which convey the passengers.
2. The track system, which supports the running gear.
3. The balustrading provided with hand rails moving at the same speed as the moving steps.

4 The drive, or machinery, necessary to operate the moving steps and hand rails.
5. The safety features designed to stop the escalator automatically in cases of emergency.
6. The structural-steel truss, or the skeleton, on which the escalator parts are carried.

There are two major types of escalators in use—the flat-step type, and the cleat-step type. On the flat-step type of escalator, the step appears from under the floor at a lower landing as a moving platform, then, as it goes upward, it slowly forms into a perfect series of steps, rising into a complete stairway. On each side there is a hand rail of flexible material, which moves upward at the same speed as the stairs, thus affording the passengers a secure support as they ascend. At the top, the steps again flatten out into a moving platform, from which the passengers step to a stationary landing on the same level, with no appreciable sensation other than that experienced in walking on the level. The ascending escalator is provided with a shunt at the upper landing which affords a place wh[illegible] th[illegible] [illegible]; platfo[illegible] dis[illegible] and at the same time guides the passengers off the escalator. This shunt is built in two styles, namely, the triangular shunt, which permits passengers to get off either side of the escalator; or the side shunt, which is built either right or left—depending upon building conditions—and permits pas-



Fig. 15.—Upper landing of flat type escalator, triangular shunt.

sengers to go off from one side of the escalator only. On the descending escalator, the shunt is located at the bottom landing, and on the reversible-type escalator, shunts are located at the top and bottom landings. This type of escalator, due to the use of the shunts, requires more floor space than the cleat-step escalator. Fig. 15 shows the upper landing of a flat-type ascending escalator, provided with the triangular shunt and also at the same time shows the lower landing of another ascending escalator directly in back of same.

The cleat-step escalator combines the best features of both the older cleat-step-type escalator and the flat-step types. Its principal features are the perfect horizontal step formation of the flat-step type and the comb landings at the top and bottom landings so as not to require the space on the floors needed for the shunts used on the flat-step type. The steps are of the same construction as the flat-step type but have longitudinal cleats fastened to the steps, so as to permit the use of the comb landings. This type of escalator should not be confused with the older cleat type, as this type has a horizontal formation of steps, as shown in Fig. 16. One of the features of this type of escalator is that it is always made reversible, so that it can readily be operated in either direction.

Escalators are built in three widths- 2 3, and 4 ft. between the fixed balustrading. The angle of incline is 30 deg. from the horizontal, and the escalators operate at a speed of 90 ft. per min. The normal carrying capacity of the escalators is as follows: 2 ft. wide, 4000 passengers per hour; 3 ft. wide, 6000 passengers per hour; and 4 ft. wide, 8000 passengers per hour.

The type of escalator most commonly installed is the cleat-step type, due to its reversible feature and the minimum space required for the installation. It has the further advantage of having straight landings at the top and bottom, so that passengers can walk directly on and off. It also does not require the use of shunts.

Escalators are found to be very advantageous in department stores, railway and subway stations, industrial buildings, theatres, amusement parks, restaurants, and wherever a large number of people must be handled in a minimum amount of time, and their use has proved to be exceedingly satisfactory for installations of this type.

22a. Department-store Escalators.—In the modern department store, both escalators and elevators are installed so as to provide the maximum amount of service with the minimum amount of equipment, and they are so arranged and located that the escalator should be the first choice when the customer enters the store, thereby relieving the elevators of the heavy interfloor traffic. The equipment installed should be so located that proper balance will be obtained between escalator and elevator traffic. Up and down escalator service should be provided to all retail-sales floors. The trip up in the escalator gives the passengers a broad



Fig. 16.—Escalator in Macy's store, New York City.

view of the entire floor and helps to familiarize them with sections of the store they might not otherwise visit.

It has been found from actual experience in a large number of stores that where escalators are installed in conjunction with elevators a great many more persons who enter the store circulate above the ground floor than in stores where only elevators are installed.

It is highly important when the building is planned to arrange the steel work so that in case escalators are not installed when the building is erected they can be added at a later date without remodeling the structure.

22b. Railway- and Subway-station Escalators.—In many railway and subway stations, the topographical conditions make it necessary to have the stations high overhead or far underground. In these cases, means of vertical transportation must be provided by the use

of either elevators or escalators. In most cases, these distances are such that the use of escalators is the most suitable means of transporting the passengers. The problem to be solved involves not only the carrying of the passengers upward in comfort and without exertion but also the very important time element. There must be no delay in moving the passengers, not only because of the time which they individually would lose but also because the train platforms are usually limited in area. The headway between trains is small, and in the majority of cases all the passengers from one train must be moved before the next train arrives.

22c. Industrial-building Escalators.—The use of escalators has been found desirable in large industrial buildings where it is necessary to carry a considerable number of employes to and from the various floors of the plant within a minimum amount of time.

23. Inclined Elevators.—The subject of freight handling is a very broad one, and the type of apparatus best suited to the work dependent upon the conditions in each individual case. In addition to vertical elevators, the inclined elevator has been found to be very useful for handling merchandise loaded on two-wheel hand trucks, as when loading and unloading from



FIG. 17 Double file incline elevator in a large department store.

the pier to the steamer where there is a varying difference in level between the deck and pier. It is also useful for the transfer of merchandise from shipping rooms to delivery platforms, such as in department stores where containers on wheels are used as storage bins in the shipping room and transferred to the delivery platform. Fig. 17 shows a double-file inclined elevator carrying trucks from shipping room to store level in a department-store installation.

24. Spiral-gravity Conveyors.—A spiral-gravity conveyor consists of a fixed spiral blade within a circular shell, used for conveying merchandise, such as packages, boxes, etc., by gravity from upper floors.

Spiral-gravity conveyors are built in two styles—open type and closed type. The open type consists of a vertical center core, spiral blade, and outside guard. The height of the outside guard depends upon the size of merchandise to be conveyed. The open-type conveyor is usually furnished only with single-blade-type conveyors. The closed conveyor consists of

a vertical center core, spiral blade, and outside shell completely surrounding the conveyor in its entire vertical height. This type of conveyor is provided with single, double, or triple blades.

The outside diameter of conveyors depends upon the size and type of merchandise to be handled and usually varies from about 3 ft. 6 in. in diameter up to about 20 ft. The average diameter of conveyors for department-store service is from 6 to 7 ft., and they are of the two- or three-blade type.

The inlets and outlets to the conveyor are located to suit the loading and unloading facilities in the building.

For the typical department-store installation, having three blades, the following operation is used: Blade No. 1 is known as an outgoing blade and handles all the sold merchandize from the upper floors to the delivery room and usually has inlets at all floors with one outlet feeding to the delivery room. The other two blades are known as stock blades and are used for sending merchandise from the stock rooms to the selling floors. They are usually arranged as follows: The first stock blade has inlets at the stock-room floors and one outlet at the first floor. The second stock blade feeds the second floor.

When it is desired to make provisions for sending merchandise to the other intermediate floors, switch plates are provided in the conveyor at these floors. A switch plate is practically a hinged shelf mounted on the conveyor shell and arranged to be thrown in and out of position manually when it is desired to receive merchandise at that particular floor or divert it to another floor.

Conveyors have also been found very useful in industrial buildings. The size, diameter, and type of conveyor, number of blades, and pitch of same are items which have to be calculated for each particular installation. Fireproof hatchways are usually provided around the conveyor where called for by local codes, and in such cases, fire-resisting doors should be provided at all inlet and outlet openings and should be of a type that complies with the code.

25. Chutes.—Rubbish and waste-paper chutes are usually provided in department stores, loft buildings, industrial buildings, etc., where there is a considerable amount of waste paper and rubbish to be sent down to the bailing room or incinerator. This type of chute consists of a vertical, rectangular flue, provided with a curved outlet at the bottom, so as to divert the material to the proper place in the bailing or incinerator room.

Inlet hoppers are provided at all floors. These hoppers should be of a design and construction so that when the material is being deposited into same, the inlet door to the chute is completely closed and is automatically opened to discharge the material when the cover of the hopper is closed, so that in the event of back draught, none of this material will be blown back into the loading floor.

26. General.—The drawings shown are somewhat conventional and sketchy. They are proposal layouts put out by the elevator contractor to indicate to the architect or engineer what is required in the way of preparation at the building for the accommodation of the elevator apparatus. Architects and engineers preparing building plans should consult with elevator contractors as early as possible in order that each situation may be considered and in order that proposal drawings similar to those shown above may be obtained before the building is planned in detail.

The number of elevators, type of control, size and shape of the cars and grouping of same, and load and speed constitute an important engineering problem that should be carefully calculated for each individual building.

The load reactions shown on the layouts are based on doubling the live loads for impact, plus the dead loads; the supports required at the reactions, and at a height shown on elevations, are not included in elevator work. These should always be furnished by another contractor.

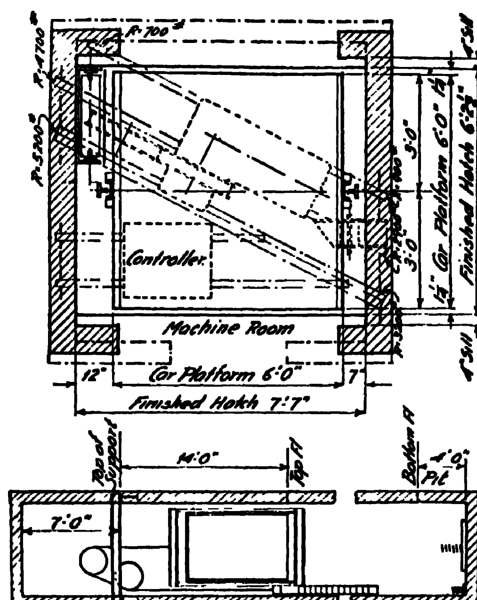


Fig. 18.—One single wrap traction freight elevator. Double button control. Duty 2500 lb. at 50 f.p.m

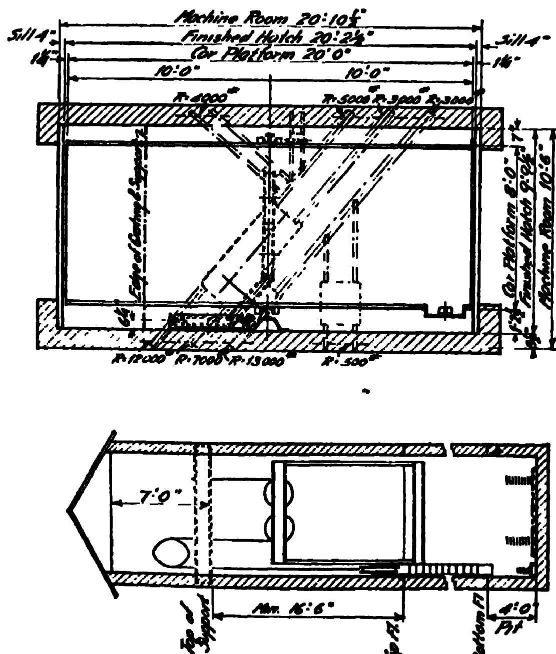


Fig. 19.—One single wrap traction garage elevator. 2:1 roping. Car switch operation. Duty 6000 lb. at 60 f.p.m

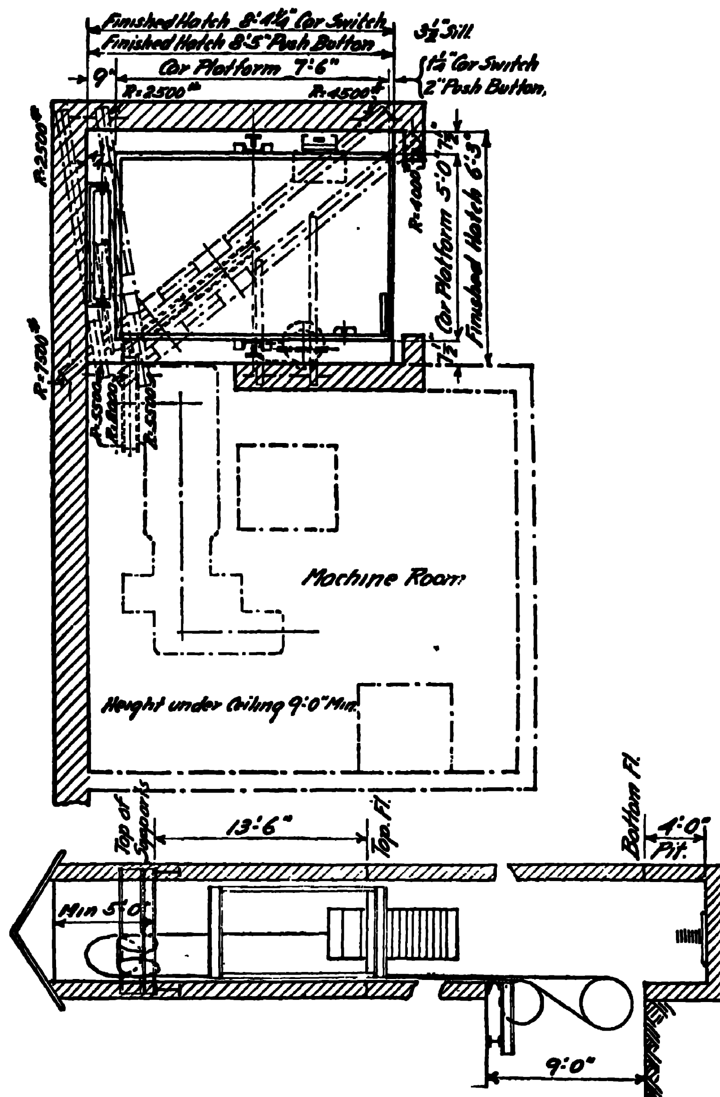


FIG. 20.—One single wrap traction micro-drive hospital elevator. Basement installation. Car switch operation. Duty 2500 lb at 150 f.p.m.

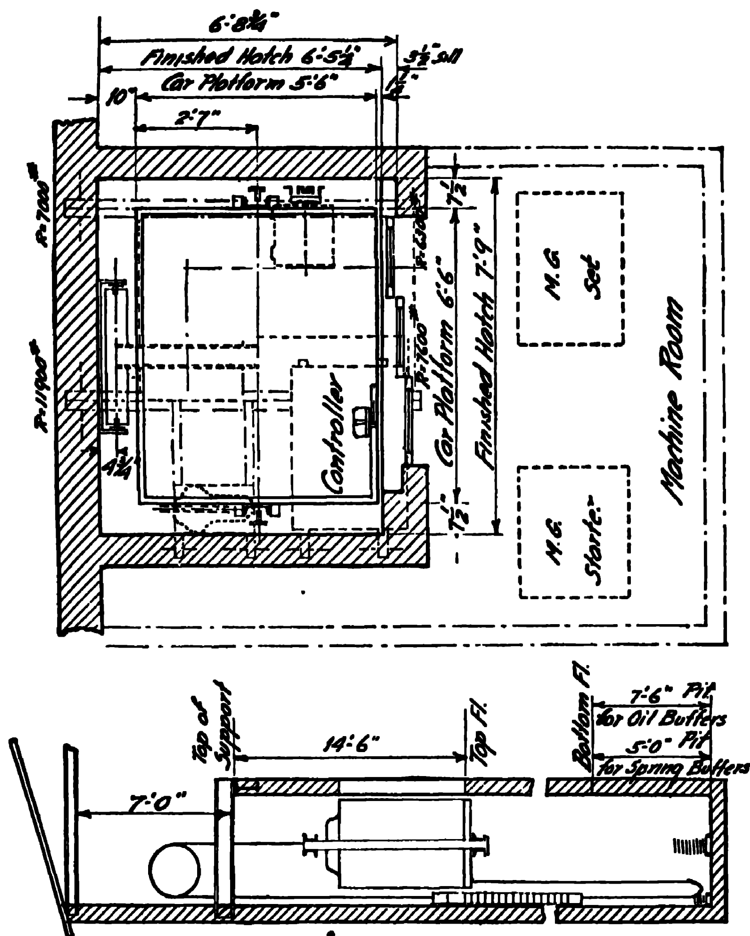


FIG. 21.—One single wrap traction passenger elevator. Unit multi-voltage control. Car switch operation. Duty 2500 lb. at 300 f.p.m.

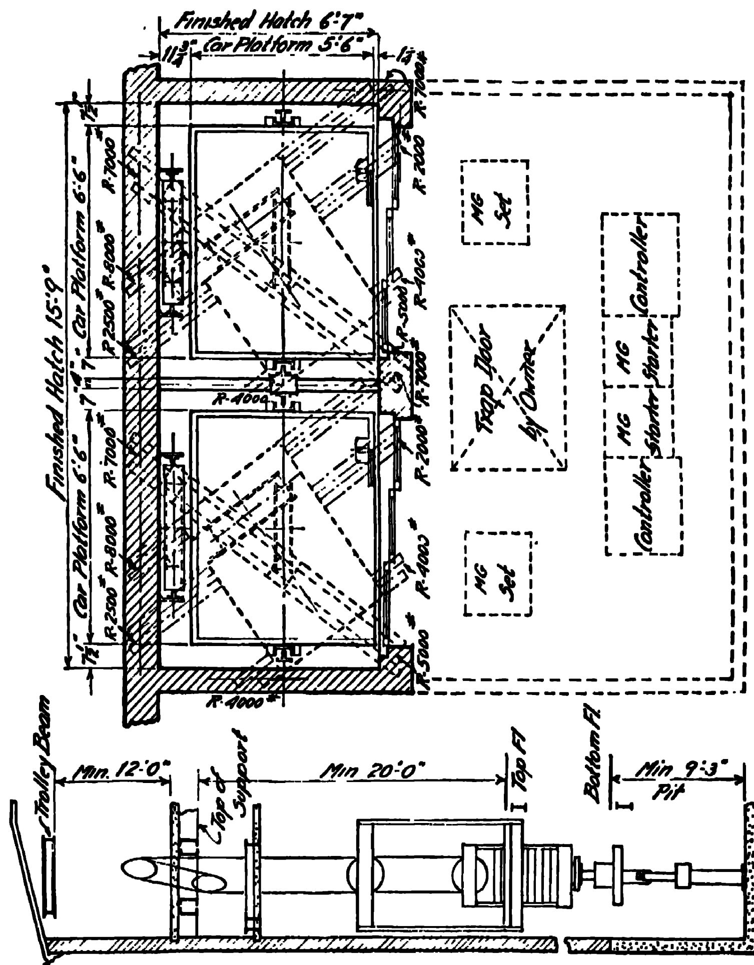


Fig. 22.—Two gearless traction passenger elevators 2:1 roping. Unit multi-voltage control. Car switch operation. Duty 2500 lb. at 450 f.p.m.

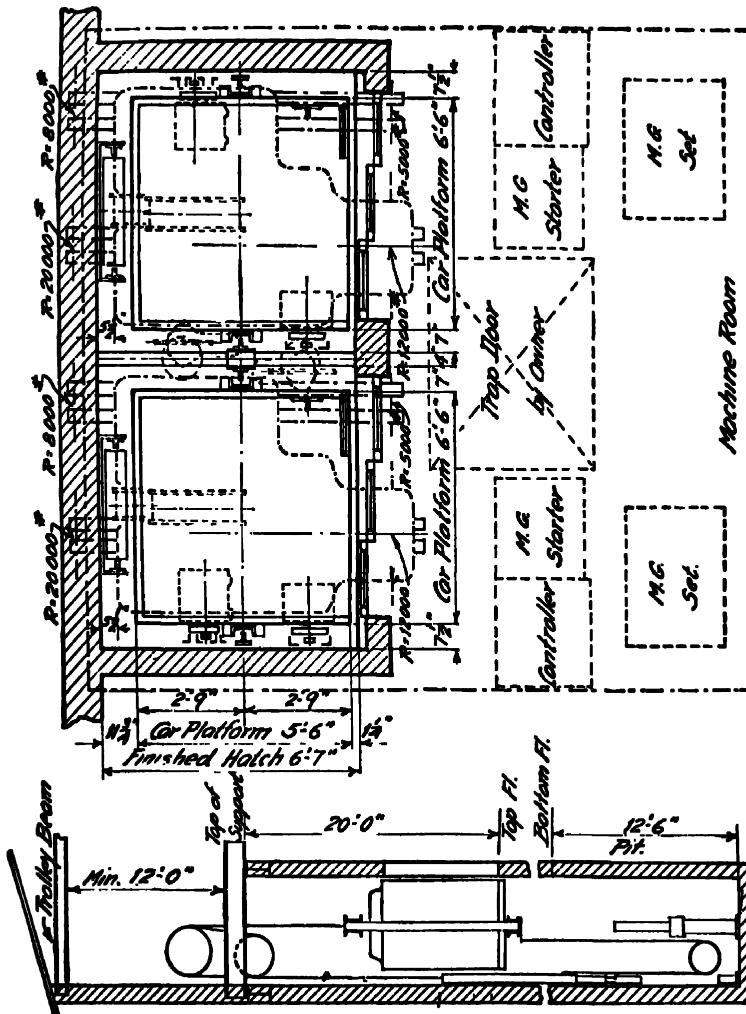


FIG. 23.—Two gearless traction micro-drive passenger elevators. Unit multi-voltage control. Car switch operation. Duty 2500 lb. at 700 f.p.m.

SECTION 11

MECHANICAL REFRIGERATION

BY STEWART T. SMITH

1. British Thermal Unit.—The unit for measuring heat is known as the British thermal unit, or briefly, the B.t.u. It is that amount of heat which is required to raise the temperature of one pound of water one degree Fahrenheit.

2. Specific Heat.—The specific heat of a substance is the ratio of the number of B.t.u. required to raise the temperature of 1 lb. of the substance 1 deg. F., to that required to raise the temperature of 1 lb. of water 1 deg. F.

3. Latent Heat.—The latent heat of a substance is the number of B.t.u. required to change the state of 1 lb. of the substance without changing the temperature. Thus the *latent heat of freezing* of a substance is the number of B.t.u. required to change 1 lb. of the substance from a liquid state to a frozen state at the same temperature. Also the *latent heat of vaporization* of a substance is the number of B.t.u. required to change 1 lb. of the substance from a liquid state to a vaporous state at the same temperature.

4. Measurement of Refrigerating Effect.—The commercial unit of refrigeration is the *ton of refrigeration* and is the number of B.t.u. required to melt (not manufacture) one ton (2000 lb.) of pure solid ice. Since the latent heat of ice is 144, the *ton of refrigeration* is equal to $2000 \times 144 = 288{,}000$ B.t.u. As all refrigerating calculations are made on a 24-hr. basis, the ton of refrigeration per day is equal to 12,000 B.t.u. per hr., or 200 B.t.u. per min., and as 1 B.t.u. is equal to 778 foot pounds and 0.293 watt hours, the ton of refrigeration is also equal to the heat given off by consuming $\frac{(12{,}000)\,(778)}{(33{,}000)\,(60)} = 4.71$ horsepower-hours and $\frac{(12{,}000)\,(0.293)}{1{,}000} = 3.51$ kilowatt-hours. These last two equivalents are useful in providing for heat given off by machinery, lights, etc.

5. Rating of Refrigerating Machines.—A refrigerating machine is rated by the number of tons of refrigeration it is capable of extracting in 24 hr. at a given pressure range and a given temperature of the condensing water. The usual rating is for 15.65 lb. suction pressure, 185 lb. discharge pressure, and 60 deg. F. condensing water.

A refrigerating machine sometimes is listed in terms of its ice making capacity, but as the refrigerating capacity varies from 1.7 to 2 times the ice making capacity, depending upon the temperature of the water to be frozen and other variables, this term should be used with caution.

6. Refrigerating Mediums.—There are two main refrigerating mediums commercially used: *ammonia* (NH_3) and carbon dioxide (CO_2). These substances are chosen because the latent heat of vaporization of each of them is high and because the liquefaction point of each is low.

Of the two substances, ammonia is the most widely used. Its liquefaction point is very low which permits the use of discharge pressure of from 150 to 210 lb. and its latent heat of vaporization is the higher of the two substances. Ammonia is also soluble in water, which makes possible the absorption system of refrigeration. The principal objection to ammonia is the offensive odor which it has and which is annoying when leaks occur.

Carbon dioxide machines are used quite frequently where small compact mach[illegible] are required, but as the boiling point of carbon dioxide is relatively high, it is necessary to have the machi[illegible]designed for exceptionally high pressures. Carbon dioxide has the advantage of having no objectional odor.

Suphur dioxide is sometimes used beause the machines operate at a low condensing pressure, but the latent heat of vaporization for sulphur dioxide is about one-third that of ammonia.

7. Commercial Systems of Refrigeration.—There are two commercial systems of refrigeration in use: the *compression* system and the *absorption* system. The compression system is the more widely used. Both systems require water to extract the heat from the refrigerating medium.

7a. Compression System.—The *compression system* is composed of the following parts: the compressor, the condenser, the liquid receiver, and the expansion coils.

The *compressor* is a machine similar to an air compressor and is driven in the same manner. The average machine is designed to run at a speed of about 75 revolutions per minute. There are, however, machines known as high speed machines which operate at about 225 r.p.m. The purpose of the compressor is to compress the gas.

The *condenser* is a coil of pipes (usually of 2-in. pipe) 12 pipes high and 20 ft. long. In the atmospheric type of condenser (Fig. 1), water trickles over the pipes, and in the double pipe condenser (Fig. 2), the gas is passed through the outer annular space while the cooling water is passed through the central pipe. An atmospheric condenser 12 pipes high and 20 ft. long under average conditions is good for 10 tons of refrigeration. It is not economical to make condensers more than 12 pipes high. The purpose of the condenser is to remove the heat from the gas and to change the state of the substance from a gaseous to a liquid state.

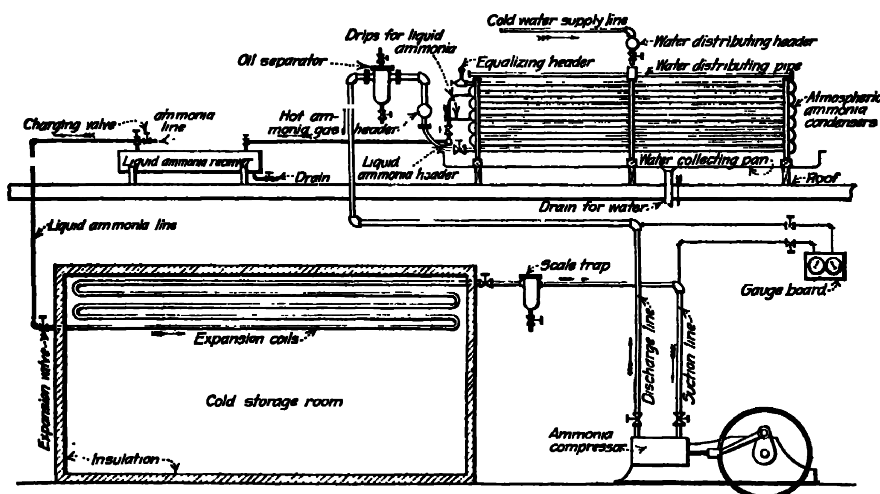


FIG. 1.—Cycle of operation of ammonia compression system of refrigeration.

The *liquid receiver* (Figs. 1 and 2) is a horizontal cylindrical drum which is used as a reservoir for the storage of the liquid refrigerating medium.

The *expansion coils* (Figs. 1 and 2) are the pipe coils in the rooms or other places where the cooling effect is desired and through which the refrigerating medium is circulated. These are usually of 1½ or 2-in. pipe.

The cycle of operation of an ammonia compression system is shown in Fig. 1, and is as follows: The ammonia gas enters the compressor at a low pressure, say 15 lb., and is there compressed to say 185 lb. In compressing the gas, heat is added to it. The gas then passes through an oil separator which removes the oil that is absorbed in passing through the compressor. It then passes through the condenser. In the condenser, the cool water passing over the pipes removes enough heat from the vapor to change it to a liquid state. The liquid ammonia thus formed then flows into the liquid receiver. This much of the system is what is known as the high pressure side of the system.

The liquid is then passed through an expansion valve to the expansion coils. In passing the expansion valve, the pressure is reduced from 185 lb. to 15 lb. In reducing the pressure 150 lb., the temperature of the liquid is reduced from 95 to 0 deg. F. The cold liquid in the expansion coils, being at a low pressure, boils away to a gas, absorbing the heat from the surrounding medium. This gas is then returned to the compressor thus completing the cycle of operation.

In operating the system, the discharge pressure is governed by the condensing water and the suction pressure is governed by the temperature desired in the rooms. If a 15 deg. difference of temperature is desired between the cooling medium and the air in a room and it is desired to keep this room at 15 deg F., the temperature of the ammonia should be 0 deg. F. By referring to tables giving the properties of ammonia, it will be noted that 0 deg. F. corresponds to a pressure of 15.65 lb. Thus the suction pressure should be 15.65 lb. After the expansion valve has been regulated to give the proper supply of ammonia to the coils, the control of the entire system is dependent on operating the compressor to maintain this suction pressure. Fig. 1 shows the various pieces of apparatus and the cycle of operation of the compression system.

Some of the advantages of the compression system of refrigeration are: (1) the use of steam is not necessarily required as a compressor can be operated by gas engine, oil engine, steam engine, or by electric motors; and (2) it is economical in operation, and very high efficiencies can be obtained where economical power is available.

The chief disadvantage the system has is the difficulty of obtaining economically, temperatures below about 0 deg. F.

7b. Absorption System.- The *absorption system* of refrigeration is composed of the following parts: the generator, the rectifier, the exchanger, the condenser, the liquid re-

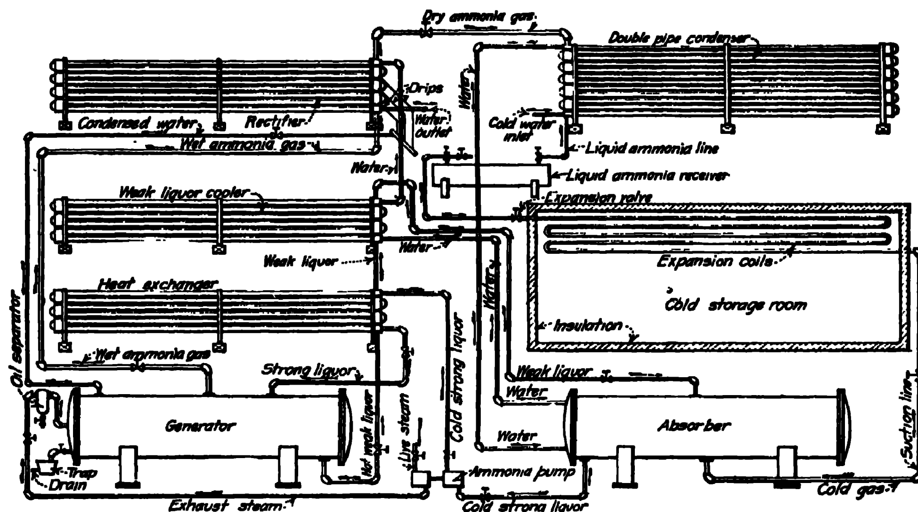


FIG. 2.—Cycle of operation of ammonia absorption system of refrigeration.

ceiver, the expansion coils, and the absorber. The absorption system uses only ammonia as a refrigerant because of its solubility in water.

The condenser, liquid receiver, and expansion coils of the two systems are identical, perform the same functions, and have the same relation to one another. With the compression system, the compressor is the heart of the system; in the same way, the absorber is the heart of the absorption system.

The *absorber* is a horizontal cylindrical drum built like a horizontal tubular boiler. Cooling water passes through the tubes and cools the liquid surrounding them, the liquid being a weak mixture of water and ammonia, termed *weak liquor*. The gas from the expansion coils is brought into the absorber at the bottom through a perforated pipe and is allowed to bubble up through the weak liquor. The ammonia gas in bubbling up through the weak liquor is absorbed by it. The liquid is thus enriched by the addition of ammonia and is now termed *strong liquor*. This strong liquor is pumped out of the absorber by means of an *ammonia pump*, the only moving part of the system. This pump is a steam-driven piston pump much like a boiler-feed pump. The strong liquor passes from the pump through a set of double pipe coils called an *exchanger*. Here the cold strong liquor in one pipe on its way to the generator, absorbs some of the heat from the hot weak liquor in the other pipe leaving the generator, and becomes warm. The warm strong liquor then passes to the generator. The *generator* is another horizontal cylindrical drum having a set of steam coils suspended in it. Exhaust steam from the ammonia pump or from

other sources is passed through this set of coils and the heat of the steam is utilized in heating the strong liquor surrounding the coils. A large part of the ammonia in the liquor and part of the water is thus turned into vapor, forming a hot wet gas, and leaving behind a hot weak liquor. The hot weak liquor is first passed through the exchanger as before mentioned and is then passed through a *weak liquor cooler* which is another set of double pipes through which water circulates as the cooling medium. The weak liquor is then passed to the absorber completing that cycle of operation.

The hot wet gas is taken from the generator through a set of pipe coils arranged with drip connections on several of the pipes. This apparatus is called the *rectifier*. Its purpose is to remove the water vapor contained in the gas. Over the pipes is passed cooling water which cools the gas sufficiently to condense the water vapor. This condensed water is carried away at the drip connections and brought back to the generator. The dry hot ammonia gas then passes to the ammonia condensers and from there to the liquid receiver and expansion coils to the absorber, thereby completing the cycle of operation. The control of the entire system is based on regulating the speed of the ammonia pump.

Fig. 2 shows the various pieces of apparatus and the two cycles of operation in the absorption system.

The advantages of the system are: (1) simplicity of control—requiring very little attention; (2) advantageous utilization of exhaust steam which is often an important factor; and (3) the ease with which low temperatures can be obtained.

The disadvantages are that the system must have steam, and that the system is of low efficiency.

8. Refrigerating Load.—The *refrigerating load* which must be carefully calculated in designing the refrigerating plant, is composed of several factors the principal ones being: transmission of heat through walls, cooling the goods, freezing the goods, condensing vapor, and offsetting heat generated within the room.

Heat transmission of walls is calculated in the same manner as for heating work. In the majority of instances where refrigeration is required, insulation is applied to the walls, and it is common practice to consider only the insulation as retarding the flow of heat through the wall.

Illustrative Problem.—Required the amount of refrigeration to offset the transmission of heat into a 2-story building 40 × 80 × 24 ft., inside measurements, with 4 in. of corkboard applied to the walls, roof, and floor. The temperature of the air in the building is to be held at 30 deg. F when the outside temperature is 90 deg. F. The temperature of the soil under the floor is considered 55 deg. F. The transmission of corkboard is approximately 6.4 B.t.u. per 24 hr. per inch of thickness.

The heat flow through the floor $= (40)(80)\left(\frac{6.4}{4}\right)(55 - 30) = 128{,}000$ B.t.u. per day.

The heat flow through the roof $= (40)(80)\left(\frac{6.4}{4}\right)(90 - 30) = 307{,}200$ B.t.u. per day.

The heat flow through the walls $= (240)(24)\left(\frac{6.4}{4}\right)(90 - 30) = \underline{552{,}960}$ B.t u. per day.

Total $= 988{,}160$ B.t.u. per day.

Amount of refrigeration required $= \frac{988{,}160}{288{,}000} = 3.43$ tons

In providing refrigeration to *cool goods*, the specific heat and the weight of the goods must be considered.

Illustrative Problem.—Required the amount of refrigeration to cool 800 crates of eggs in one day from 75 to 33 deg. F.

One crate of eggs weighs 70 lb. and the specific heat of eggs is 0.76. The amount of refrigeration $= (800)(70)(0.76)(75 - 33) = 1{,}787{,}520$ B.t.u. =

$$\frac{1{,}787{,}520}{288{,}000} = 6.206 \text{ tons.}$$

Where it is necessary to *freeze the goods*, the latent heat of freezing as well as the specific heat above and below freezing must be considered.

Illustrative Problem.—Required the amount of refrigeration to cool in one day's time, 100 hogs weighing 250 lb. each, from 80 to 15 deg. F.

From tables, the specific heat above freezing = 0.51, the specific heat below freezing = 0.30, and the latent heat of freezing = 55.

B.t.u. required to cool goods to freezing point	$= (100)(250)(0.51)(80 - 32)$	$= 612{,}000$
B.t.u. required to freeze goods	$= (100)(250)(55)$	$= 1{,}375{,}000$
B.t.u. required to cool goods from 32 to 15 deg. F.	$= (100)(250)(0.3)(32 - 15)$	$= \underline{127{,}000}$
	Total	$= 2{,}114{,}500$

Amount of refrigeration required $= \frac{2{,}114{,}500}{288{,}000} = 7.34$ tons.

To calculate the amount of refrigeration required to *condense moisture* out of air, the designer should have available a psychrometric chart. A very convenient chart for this work is made by the Carrier Engineering Corporation of New York City. When 1 lb. of moisture is condensed to water, approximately 1100 B.t.u. are given up by the vapor. Thus, if a quantity of air is to be cooled below its saturation point, the heat given off by the vapor condensed must be absorbed by the refrigerating coils.

Illustrative Problem.—Required the amount of refrigeration to cool in 1 hour 100,000 cu. ft. of air from 85 deg. F. and 70 % humidity to 15 deg. F.

The amount of moisture in air at 85 deg. F. and 70 % saturation, as shown by charts or tables, is 1.273 lb. per 1000 cu. ft. Air at 15 deg. F. and 100 % saturation is found to contain 0.14 lb. per 1000 cu. ft. There must therefore be condensed (1.133)(100) = 113.3 lb. of water which will require (113.3)(1100) = 124,630 B.t.u. The specific heat of air is 0.237. The weight of air at the average temperature of 50 deg. F. is 0.078 lb. per cu. ft. Thus, the heat given up by cooling the air = (100,000)(0.237)(0.078)(85 − 15) = 129,402 B.t.u. The amount of refrigeration needed is thus

$$\frac{124,630 + 129,402}{12,000} = 21.17 \text{ tons}$$

For very accurate work such as is required in the laboratory, calculations should be based on the weight of the air instead of the volume, and as the curve showing the ratio between temperature and weight of air is not a straight line, it is not absolutely accurate to take the weight of the air at the average temperature, but the method as outlined here is one that is used by many designers. In fact, the value of 0.018 is commonly taken as the heat extracted in lowering the temperature of 1 cu. ft. of air regardless of the temperature.

Heat generated within a room is easily accounted for by the use of the power equivalent for 1 ton of refrigeration. A motor running in a room gives off in heat the difference between the efficiency of the motor and 100%. In other words, if the motor is 85% efficient, 15% of the horsepower of the motor goes into heat.

One hundred 50-watt lamps in a room will require $\frac{100 \times 50}{1000} = 5$ kw. per hour or $\frac{5}{3.51} =$ 1.42 tons.

	B.t.u. per hour
One 16-c.p. incandescent lamp gives off	160
One gas light gives off approximately	3600
One workman gives off approximately	500

In commercial practice a factor should be added to those items which are easily figured to cover inefficiency of insulation, opening of doors, and other items. This percentage varies from 10 to 25%. There is a safe rule which can be followed for cold-storage rooms, not including freezer rooms, as follows: Calculate the heat transfer through the walls, floor, and ceiling of the room on the basis of 12 B.t.u per day per deg. difference of temperature for 1-in.-thick corkboard. Do not place any insulating value on ordinary building materials. Multiply the result thus obtained by the following factors to get the total refrigerating load for the room.

Room size, cubic feet	Factors
Up to 1000	3.6
1000 to 5000	3.2
5000 to 100,000	2.9
Over 100,000	2.5

In using these factors, no calculations need be made for cooling of goods, heat given off in rooms, or opening and closing of doors.

9. Methods of Application of Mechanical Refrigeration.—Refrigeration is applied in two ways: (1) the direct-expansion system, and (2) the brine circulating system.

In the *direct-expansion system* the expansion coils are placed in the rooms as in Figs. 1 and 2. The liquid ammonia is expanded in them and allowed to boil away, absorbing heat from the air surrounding the pipes. This system is used where very low temperatures are desired, and where a flexible system is not necessary. Ice storage houses, sharp freezers, and meat boxes are usually provided with the direct expansion system. The greatest objection to the system is that the cooling effect of the ammonia stops as soon as the compressor stops.

In the *brine circulating system* the ammonia is allowed to expand into a cylindrical drum called a brine cooler. Coils, through which brine is pumped, are placed in the drum. The ammonia in boiling away, absorbs the heat from the brine. The brine is then pumped through pipes arranged in the room the same as for the direct expansion system. The great advantage this system has is in its flexibility. Due to the body of brine which is cold, if for any reason it is necessary to stop the compressor, refrigeration can be obtained for several hours by circulating the brine. There must be a certain range of temperature between the ammonia and the brine, and another range between the brine and the air in the room in order to transfer heat. Thus, it is not possible to obtain as low a temperature in the room with this system as can be obtained with the direct expansion system. This system is used particularly in cold-storage plants, and places where very perishable goods are kept, in creamery machinery, and for ice-cream-making machinery.

10. Proportioning of Cooling Surface.—The correct proportioning of the cooling surface and the arrangement of the cooling coils in the room, is as important as calculating the refrigerating load. Even though the compressor is large enough to provide for the load, if the cooling

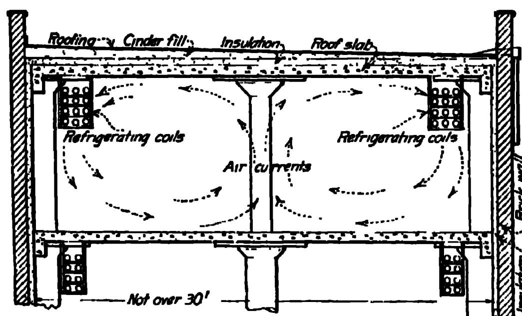


Fig. 3.—Arrangement of refrigerating coils for rooms not over 30 ft. wide.

coils are not ample or properly located, the results will not be satisfactory. In general, pipe in still air with a 12-deg. range in temperature, will transfer 2 B.t.u. per hr. per sq. ft., per 1 deg. F. difference between the temperature of the air and the temperature of the cooling medium. Where pipe is submerged in a liquid, as is the case where coils are located in the brine of an ice making tank, the heat transfer value is about 25 B.t.u.

After the heat transfer value of the pipe is determined, the range of temperature that will be used between the medium cooled and the cooling medium is decided. The greater this range is, the lower the suction pressure must be, and consequently, the greater amount of power will be required; on the other hand, the greater the range, the smaller the amount of pipe required. The amount of pipe to use and the range of temperature to use, therefore, is determined by good judgment of economical considerations. For temperatures in a room of over 20 deg. F., a temperature range of 15 deg. is used; for temperatures of between 10 and 20 deg. F., a range of 10 deg. is used; and from minus 10 deg. F. to plus 10 deg. F., or even lower, a range of 5 deg. is used.

In laying out the arrangement of coils in the rooms, the designer should bear in mind that cold air is heavier than warm air. For this reason, the coils should be so located that a natural circulation of the air is obtained. In general, coils should never be located on the four sides of a room, as by such an arrangement the natural circulation of the air is stopped. The same amount of pipe placed in coils on the two opposite sides of a room will give far better results, as by such an arrangement the air will flow down the walls, along the floor, up the center of the room, and along the ceiling to the wall (see Fig. 3). If the room is more than 30 ft. wide, there should be coils located near the center of the room as in Fig. 4. The coils should be supported near the ceiling and preferably over a passageway. The best results are obtained when

the coils are placed in the upper third of the room. Less storage space is thus taken up by the pipes, and the flow of the air is not obstructed under the pipe. Where goods are packed very solidly over the floor area, the circulation of air is sometimes helped by placing the goods on 2 × 4-in. pieces, thus making a passage for the air on the floor. However, in most cases, the air passes through the goods without this provision. In meat cooler rooms and in some cold

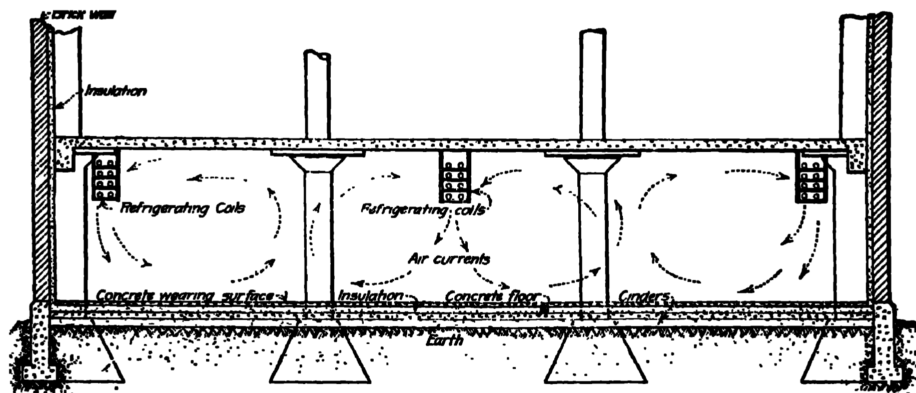


Fig. 4.—Arrangement of refrigerating coils for rooms over 30 ft. wide.

storage work where temperatures below freezing are needful, it is necessary to support under the coils, a trough to carry away the water caused by the melting of the frost which will accumulate on the coils.

Where meat is cooled in the carcass, as is the case in packing house work, the bunker system of placing the cooling coils is used (see Fig. 5). With this system, an overhead bunker is made with provisions for air to circulate over the coils and through a slot in the bunker floor to the main room below. The air circulates by gravity

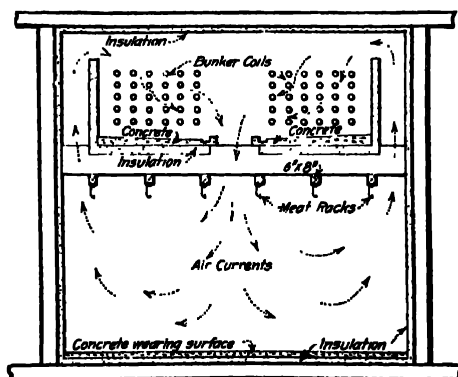


Fig. 5.—Arrangement of refrigerating coils in bunkers.

over the coils and the water caused by the melting of the frost on the pipes, is carried off by a drain in the bunker floor. For some work, these bunkers are placed outside the room to be cooled, and the air is circulated by fans over the coils and to the room through ducts. This system was used to a great extent in the past in fur storage houses and in chocolate factories.

The arrangement of the cooling coils for cooling a large amount of air to be circulated through rooms, should be such that the cooling pipes are long and close together. The air should be blown along the pipes (not across). With pipes placed on 4-in. centers and 60 ft. long, the air travels a long distance in contact with the cold pipes,

thus bringing in a time element which is important. The friction of the brine or ammonia in the pipes is also much less than where a large number of short pipes are used, thus requiring much less power.

In small refrigerator boxes, as in hotels and restaurants, usually no provision can be made to provide for natural circulation as the space is very small and the goods to be cooled are placed very near the pipes. In meat boxes, it is usually possible to place the pipe near the ceiling at the side so that a circulation can be obtained.

11. Ice Manufacturing Plants.—There are three systems for making ice that are commercially successful: (1) the plate system, (2) the distilled-water can system, and (3) the raw-water can system.

In the *plate system*, a steel tank 10 or 12 ft. deep and of varying widths and lengths, depending upon the capacity, has arranged in and across it, expansion coils on 32-in. centers for the full height. The pipes in the coils are usually on 6-in. centers and are bolted between two ⅛-in. steel plates. The tank is filled with water and the ammonia boiling away in the coil absorbs the heat in the water causing ice to form on the steel plates. While the freezing operation is going on, air is allowed to bubble up over the freezing edge thereby cleaning the surface of air bubbles and foreign matter. The result is a clear cake of ice. This operation is continued until the ice is 12 in. thick. It requires 6 days to freeze the cake of ice. Hot ammonia gas is then turned into the coils until the frozen cake is melted free of the steel plate. The cake is then lifted out of the tank by a crane and is carried to a tipping table where it is brought to a horizontal position and cut up to commerical sizes by means of a circular saw. This type of plant is very economical in operation but is high in first cost. There is also the objection that many cakes are so cracked or otherwise broken before they are finally disposed of, that there is an excessive loss of ice.

In the *distilled-water can system*, steel cans of commercial sizes are surrounded by brine in a steel freezing tank. Three 100-lb. cakes are most commonly used. The cans for this size of cake are 11½ × 22½ × 44 in. These cans are set in a tank 48 in. deep and are placed on 25-in. centers lengthwise of the tank and on 15-in. centers across the tank. Between the cans and running lengthwise of the tank, expansion coils are placed, usually 6 pipes high and on 7-in. centers. The ammonia in the coils cools the brine which in turn freezes the water in the can. The brine in the tank is kept in motion along the coils by a motor-driven propeller. There is installed in the plant a water-distilling system through which all the water for the cans passes. The water thus being free of all foreign matter, freezes clear in the cans. When the water in the can is frozen (which requires about 48 hr. for a 300-lb. cake), the can with the ice is lifted out of the tank and lowered into a tank containing hot water. It is left here sufficiently long to thaw the ice cake free of the can. The can is then lifted and placed on a can dump where the cake of ice is dumped out and passed to the ice storage room. This system, until the last few years, was the system which was most commonly installed. The objections to it are: low economy, and the necessity of having in conjunction with the plant a distilling apparatus, thus requiring steam.

The *raw-water can system* is identical with the distilled water can system in so far as the arrangement of the cans in the tank is concerned. The difference is in the use of raw water (city water) instead of distilled water. There is installed in the plant an air compressor which forces air through pipes to the freezing tank. This air is piped to the bottom of the can of water and allowed to bubble up through the water. As the water freezes in the can, this air keeps the surface washed free of air bubbles and foreign matter, thus forming a clear cake of ice. The advantages of this system are: a steam plant is not necessary as the plant can be electrically driven or otherwise, depending on kinds of power available; and better economics are obtained than with the other types. A raw water can plant may easily be made to produce 20 tons of ice per ton of coal, whereas 6 to 10 tons of ice per ton of coal is about all that can be expected of a distilled water plant. During the past few years the raw water plant has been installed almost exclusively and due to the high economies which are possible only with this type, many old style plants have been converted from the distilled system to a high duty raw water system.

12. Determination of Size of Ice Plant.—The amount of ice which can be sold in a given community is usually known or can be easily estimated. If no large storage house is available

for the storage of ice, the ice plant should be made large enough to supply the demand, running at full capacity for 200 days per year. The daily tonnage of the plant is thus determined. The freezing tank is then made large enough to accommodate 14 to 18 cans (300 lb. each) per ton of ice making capacity; 16 cans per ton is most commonly used. The larger the number of cans per ton the more economical the plant, as the time of freezing is lengthened.

13. Ice Storage Buildings.—In connection with ice making plants, there are built ice storage buildings. There is always a daily ice storage room where the ice is stored to be used immediately. Where the plant is large enough to supply the entire demand by running only during the ice season, this room is all the space that is required. A daily ice storage room should be designed to provide for a four day's supply of the freezing tank. The ceiling height is low, usually 8 ft., and the expansion pipe is arranged below the ceiling on 10-in. centers the entire length and width of the room. The room should be large enough to accommodate the ice standing on end, one cake high. 12 sq. ft. per ton of ice should be used in determining the size of the building under these conditions.

It is usually more economical to provide a large ice storage building for the storage of ice made during the winter months, and build the ice plant only large enough to provide for the demand by operating 300 days per year. Ice storage buildings, however, are not advisable unless they can be built for at least 2000-tons capacity. The larger the storage building, the better. They should be 30 to 40 ft. high and should have an area unobstructed by columns below the roof. The expansion coils are supported by hangers along the walls near the ceiling. The buildings are designed for 40 cu. ft. per ton of ice. The weight of ice is 57½ lb. per cu. ft.

14. Practical Notes.—All systems of refrigeration require water to be circulated over the ammonia condensers. The amount of water which must be provided for this work is approximately 3 gal. per min. per ton of refrigeration. Where it is necessary to use city water for this cooling work, the same water can be used over and over again by means of a cooling tower. A tower should be on a high portion of the building where it has free access to air currents.

1¼ and 2-in. pipes are most commonly used for cooling coils. The friction of the cooling medium in the pipe becomes excessive when pipe smaller than 1¼ in. is used; and when a pipe larger than 2 in. is used, the cooling surface is too small for the volume of the pipe.

In designing buildings where refrigeration is used, the following floor loads per sq. ft. may be used: in cold storage plants, 175 to 250 lb. depending upon the goods to be stored; under freezing tanks, 375 lb. for 300-lb. can tanks; and under ice storage rooms, use 60 lb. per cu. ft. for the weight of the ice.

In still air, 3000 lin. ft. of 1¼-in. pipe can be used for one expansion valve. When the pipe is submerged in brine, as is the case in a freezing tank, not more than 600 lin. ft. should be used.

Four inches of corkboard insulation should be used on rooms where a temperature of 25 to 35 deg. F. is to be obtained; 6 in. should be used for temperatures of from 0 to 25 deg. F.; and 8 in. should be used for temperatures below this. Four inches of insulation is sufficient under freezing tanks, although some designers prefer 6 in.; 12 in. of granulated cork is used around the side of freezing tanks. Insulation for cold storage buildings should not be broken at each floor but should be continuous and should be laid on top of the roof construction and between layers of concrete on the floor, as in Figs. 3 and 4. Insulation on the floor of a room should be protected by 3 to 4 in. of concrete as in Fig. 4.

The amount of power required per ton of refrigeration naturally varies with the design of the plant. An average figure is 1.5 h.p. In the summer months the amount of power required will be about 1.75 h.p., and during the winter months, this rate will be about 1.3 h.p. Absorption machines require about 35 lb. of steam per hour per ton of refrigeration.

Electricity at 1 ct. per kw.-hr. and coal at $4 per ton can be considered as equivalent when considering power costs of a plant of equal efficiency.

The average plant requires for make up purposes, 1 lb. of ammonia per 10 tons of refrigeration.

PROPERTIES OF FOOD PRODUCTS KEPT IN COLD STORAGE

Product	Temperature carried	Specific heat		Latent heat of freezing
		Above freezing	Below freezing	
Apples	32–33	0.92		
Beef frozen	0–15	0.77	0.41	102
Butter	0	0.64		84
Cabbage	33	0.93	0.48	129
Carrots	33	0.87	0.45	118
Cheese	33	0.64		
Cream	33	0.68	0.38	84
Eggs	30-32	0.76	0.40	100
Fish—dried	0 15	0.58	0.43	111
Fish—fresh—frozen	0 15	0.82	0.43	111
Fruits—fresh	32–36	0.92		
Fruits—dried	35–40	0.84		
Game to freeze	0–15	0.80	0.42	105
Ice	25	1.00	0.504	144
Ice cream	0	0.75	0.38	82
Lobster		0.81	0.42	108
Milk	35	0.90	0.47	124
Oysters	35	0.84	0.44	114
Pork	36	0.51	0.30	55
Potatoes	34	0.80	0.42	105
Poultry	0–15	0.78		102
Veal	32–36	0.70	0.39	90
Vegetables	31–35	0.91		

15. Domestic Installations.– There are many firms making mechanical refrigerators in sizes suitable for use in small, medium, and large residences.

The refrigerating medium used in domestic units may be sulphur dioxide, ammonia, ethyl chloride, unethyl chloride, dielene, carbon dioxide, etc. Many companies use a brine tank in connection with the refrigerating medium. A calcium chloride solution is commonly used for the brine. One company (the Frigidaire Corporation) uses sulphur dioxide with expansion coils and without a brine tank. The operating power is usually a small electric motor plugged into an electric socket.

Most of the domestic types of mechanical (usually called "electric") refrigerators have given satisfaction, and their use is increasing.

SECTION 12

COMMUNICATING SYSTEMS

By C. M. Jansky

The modern method of oral communication between persons at some distance apart is by some form of the telephone. The particular kind of telephone system to be installed in any case will depend upon local conditions, such as distance and the publicity or privacy of the system. If the general public is to be permitted to communicate at pleasure with persons in the building, then undoubtedly the telephone connections will be made with the central telephone exchange. If the number of calls are relatively few and concern only a few people, then each telephone may be connected directly with the central office. On the other hand, where any one of a number of persons may be called or may wish to communicate with persons outside of the building, there is usually installed a local or private branch exchange. By private branch exchange is meant a telephone system complete in itself and adapted to bring into communication any two subscribers in a comparatively small community, such as a business establishment or hotel, or any of these subscribers with any of those connected to a regular exchange. Such an intercommunicating system is usually installed by the telephone company in accordance with its specifications and is maintained by it. Where a private branch exchange switchboard or a basement terminal is installed, it is necessary to carry at least two wires from each telephone to the central distributing point in the building. Where these buildings are served by means of a cable, it is generally necessary to extend a building cable and establish one or more branch terminals, from which the distribution wires are taken. Hence, the importance of making adequate provision in advance for such cabling and wiring. It is advisable to have such provision in the building plans, otherwise the walls may be disfigured by unsightly open wiring, or it may be necessary to make openings through walls, floors, and partitions after the completion of the building. All details for making these provisions will be furnished by the telephone company to the architect or builder upon request and consultation.

1. Location of Distributing Frame.[1]—Local conditions will often determine the location of the distributing frame. There are, nevertheless, some general considerations which should be heeded. Where conditions permit, the frame is often mounted on the wall behind the switchboard. Whether such a location is possible will depend upon the point of entrance of the cables from the outside. In every case it is advisable to locate the frame as near to the switchboard and as near the point of entrance of the cables as conditions will permit, thus reducing to a minimum the length of cable. The frame should always be mounted where it will be easily accessible for repairs and where it will not be subject to dampness and mechanical injury. From the frame the wires are carried to the switchboard through switchboard cables along a cable rack, or in a wooden conduit 3 to 4 in. square in cross section. This cable runway is fastened to a wall or railing, or is supported a short distance above the floor by means of supporting iron frame work. The distributing frame and cable rack should be securely bolted together and fastened to the wall and floor with lag screws.

2. Location of Switchboard.[1]—The private branch exchange switchboard should be located on a solid floor free from vibration, and, if a lamp signal board, in a position such that strong light will not shine on its face so as to subdue the lamp signals. Where a distributing frame is not mounted behind it, the switchboard should be placed not less than 18 in. from a wall or railing so as to permit inspection freely. Where a frame is installed behind the board, a space should be left between the two so as to permit free access to the frame connections and to the back of the board.

[1] Specifications of The American Telephone and Telegraph Co.

Sometimes, in place of a distributing frame, a cross connecting box is used. This should be located where it will be free from dampness and mechanical injury, and where it is easily accessible for inspection and repairs. It is often placed near a pipe, elevator, or dumb waiter shaft so that the distributing wires and cables can be run directly to the different floors. A typical installation of cables, switchboard, cross connecting box, etc., is shown in Fig. 1.

3. Telephone Wiring Classification.[1]—It is customary to divide buildings for wiring purposes into three classes: apartment buildings, offices, and hotels. Under the term apartment buildings are included all those larger than single houses or stores and smaller than office buildings. Such buildings may contain living and office apartments, and also stores, generally on the ground floor.

In an apartment building the maximum number of telephones is seldom more than one per apartment. The class of service, however, is very difficult to forecast. In planning communication facilities for such buildings, it is advisable to provide for one circuit from each telephone to the distributing center.

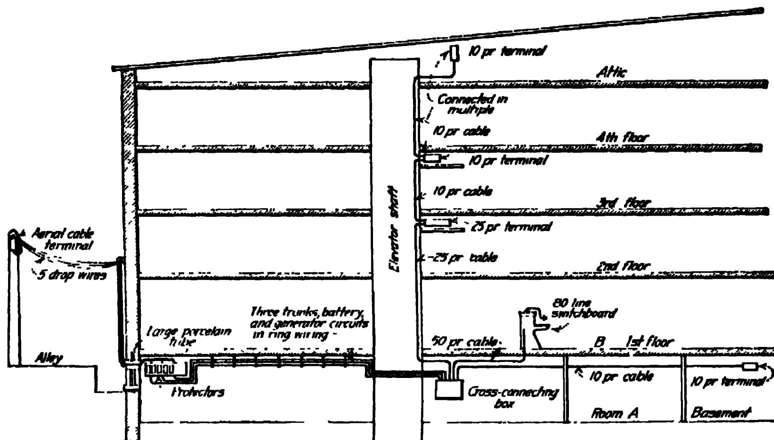


FIG. 1.

To make satisfactory and adequate provision for a communication system for an office building is a difficult problem for many reasons: The number of telephones to be installed will depend upon the character of the business, location of building, requirements of individual tenants, business of tenant, and duration of tenancy.

When planning for a communication system for an office building, provision should be made for the installation of one or more private branch exchanges as well as a central distributing basement terminal at which the service cables end.

The wiring provisions for a hotel will depend upon the size, location, type, and kind of building. Usually provision should be made for at least one private branch exchange and a basement terminal.

4. Installation of Subscribers' Sets.—By subscriber's set is meant the patron's telephone together with all necessary wiring from the terminal board. As a result of many years' experience, the telephone companies have developed certain standard methods of installation which have proved satisfactory in practice.

As a rule the telephone proper, that is, receiver and transmitter, are located to suit the convenience of the user. As a general rule it may be stated that the telephone should be located in a light and quiet place. A wall set should be mounted so that the center of the transmitter with face vertical is about 4 ft. 9 in. above the floor. The wall should be solid or some other support should be used to avoid vibration. The set should not be located near grounded metallic objects, such as radiators, registers, sinks, water and steam pipes, or near electric fixtures, because of the possibility of the patron receiving electric shock. In business offices where the telephone is frequently used by one person, it is customary to mount the set or some parts of

[1] American Telephone and Telegraph Company's Specifications.

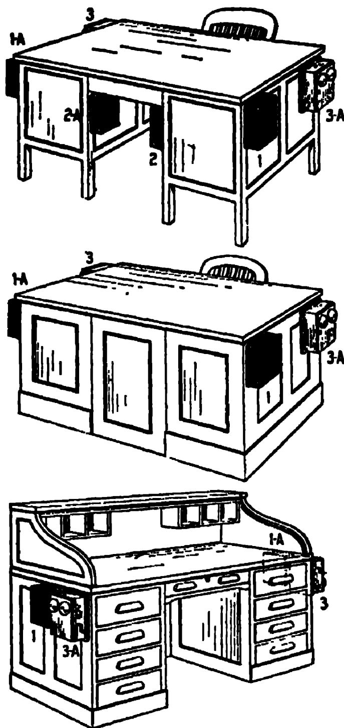


Fig. 2.

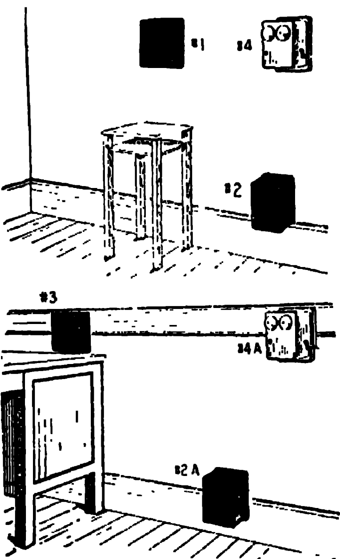


Fig. 3.

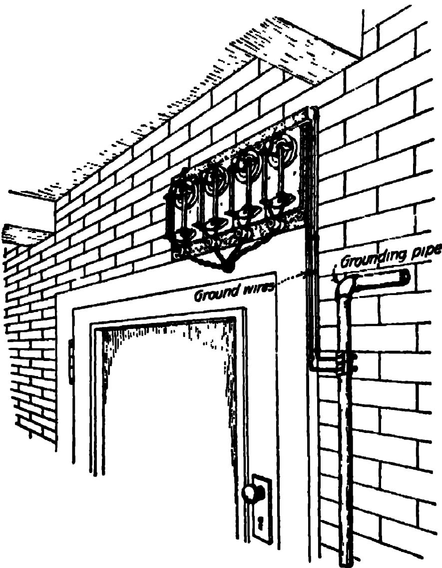
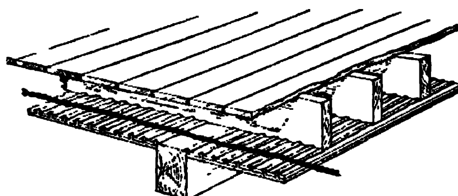
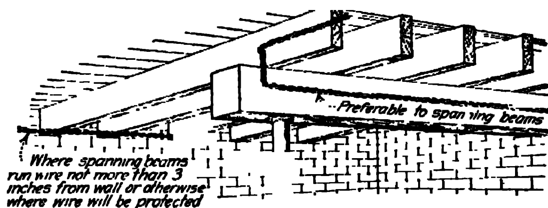


Fig. 4.

it on the patron's desk. Fig. 2[1] shows the most desirable locations. Locations 1 and 1-A are preferable for mounting the bell boxes of a common battery desk set. If it is desired to conceal the box, it may be mounted under the desk at locations indicated by 2 and 2-A.



Cellar with Lath and Plaster Ceiling



Cellar without Lath and Plaster Ceiling

Fig. 5.

Since the ringer of the magneto set must be conveniently accessible to the user, the best locations for it are at 3 or 3-A. Another method of disposing of the ringer box for desk sets is shown in Fig. 3.

5. Substation Wiring.—When the locations for the telephones have been selected, consideration should be given to the best means of running the wiring, and if possible, provisions should

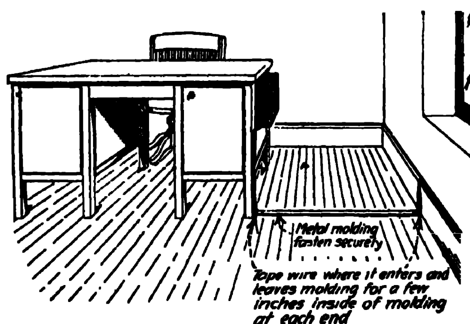
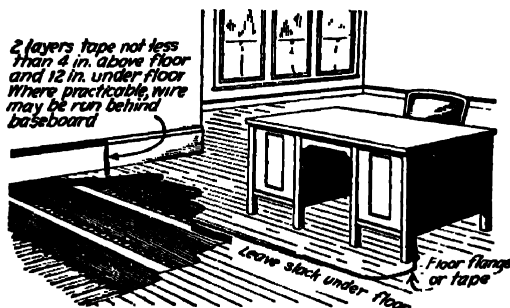


Fig. 6.

be made for concealing them. When no private branch exchange is to be installed, the wires are usually brought into the building, as shown in Fig. 4. From the protectors the wires are then run to the subscriber's sets. The routes to be followed and the type of installation to be employed will depend upon local conditions. The route should be as direct as possible and

[1] Specifications of The American Telephone and Telegraph Co.

all wiring should be inconspicuous and protected. Figs. 5 to 9 inclusive show how this problem is solved under different conditions.



6. Intercommunicating Telephones.—While all telephone systems permit intercommunication, the terms intercommunicating telephones, or interphones, is used to designate the arrangement of several sets of telephones such that any station can call any other station without

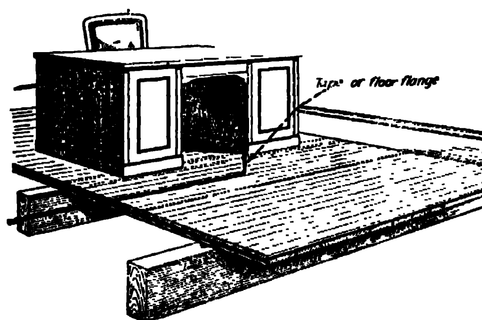


Fig. 8.

the assistance of a central operator. Such systems are used extensively in factories, offices, apartment buildings, stores, and large private dwellings as they afford a ready means of communication between different departments.

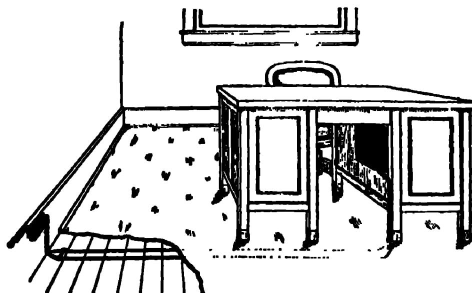


Fig. 9.

Telephone systems for intercommunication may be operated either by a local battery for the talking circuit and a magneto for signalling, or they may be operated entirely from a common battery. When the common battery type is used, two sets of batteries are invariably employed.

The most simple system of the local battery type is one in which two telephone sets are connected by a single line. Such a system needs no further discussion. However, when more than two stations make up the system, the arrangement is more complex. Of course, all the instruments could be connected to a single party line, but

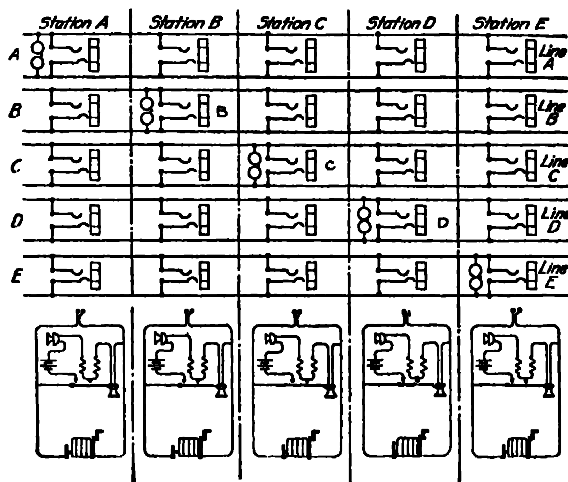


Fig. 10.

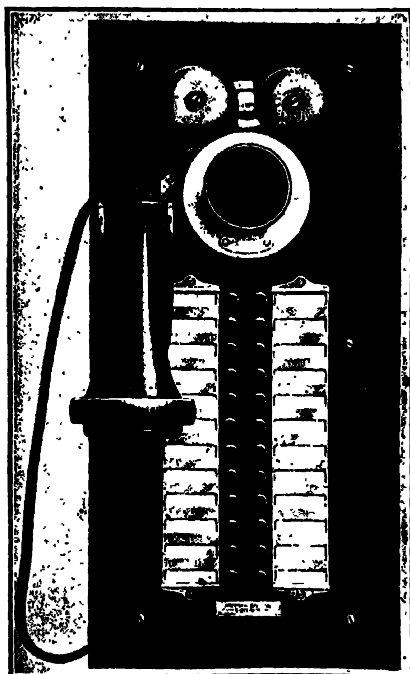


Fig. 11.

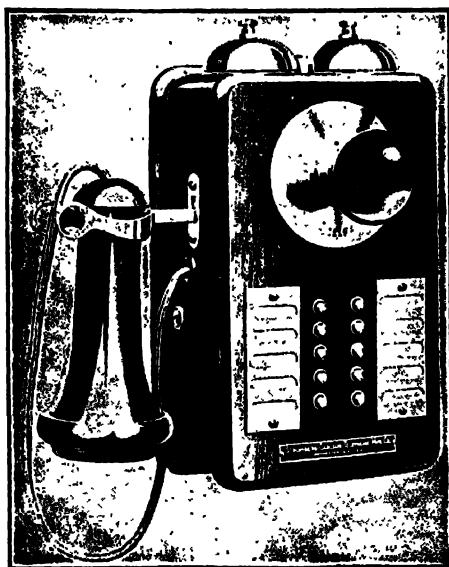
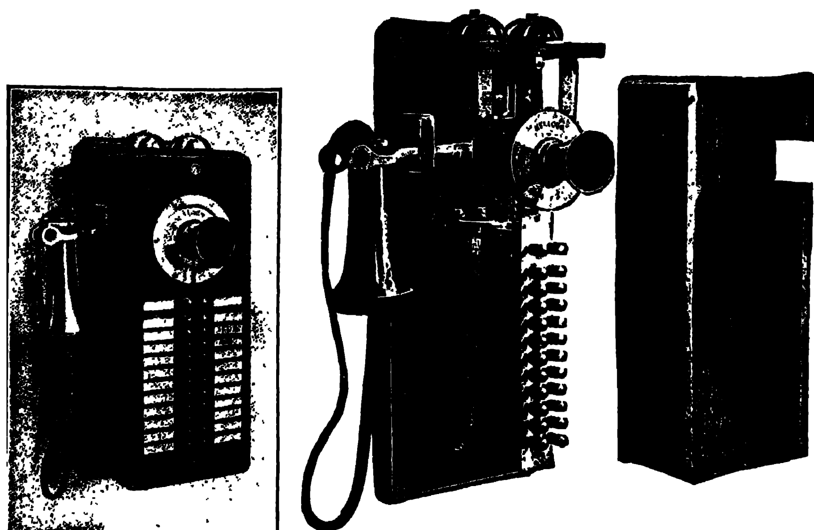


Fig. 12.

this would necessitate code ringing. The usual arrangement of intercommunicating systems is to have a separate line run from each instrument to every other one of the system. For magneto ringing, the circuits are quite simple and easily designed. Each station is provided with a panel upon which are mounted as many jacks as



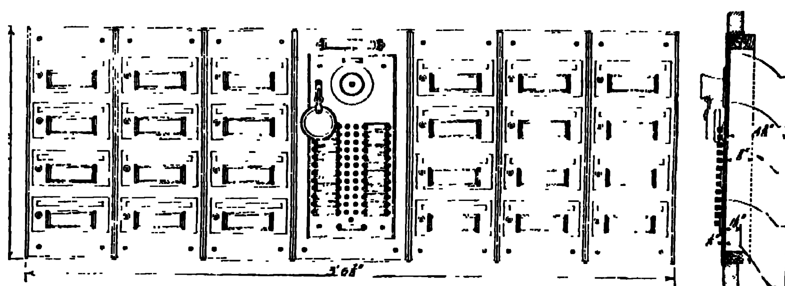


Fig. 14.

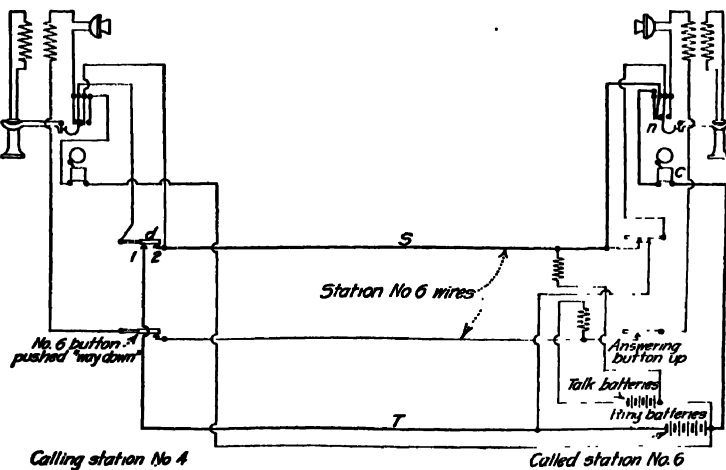

S
d
1 2
Station No 6 wires
No. 6 button pushed "way down"
Answering button up
Talk batteries
Ring batteries
T
Calling station No 4
Called station No. 6

Fig. 15.

there are stations, and lines running from any one station connect the jacks into as many parallel groups as there are stations At each station the ringer is bridged across one line. This line is designated at all other stations as belonging to the station at which the bells are bridged. The talking and ringing circuit at each station is provided with a terminal plug which is used to make connection with the jack of any other station. Fig. 10 is a simplified diagram of such a system. When a person at station *A* wishes to call some one at station *D*, he inserts the plug into the jack connected to the *D* line and turns the magneto. As the only ringer that is bridged across this line is at station *D* it is the only station that will hear the call. As soon as the person at station *D* inserts his plug in jack *D*, the talking circuit with station *A* is complete.

Although such a system is extremely simple, owing to the convenience of automatic signalling provided by the common battery system, the latter is displacing it.

7. Common Battery Interphone Systems.—Most of the manufacturers of standard telephone apparatus also manufacture intercommunicating telephone apparatus. In general the principles of operation of the different makes are the same, but each has some distinctive method of connection for ringing.

At each station is a telephone set, either a wall set containing the keys and talking set, or a desk stand with a separate key box. Each wall set, or desk set key box has a series of buttons,

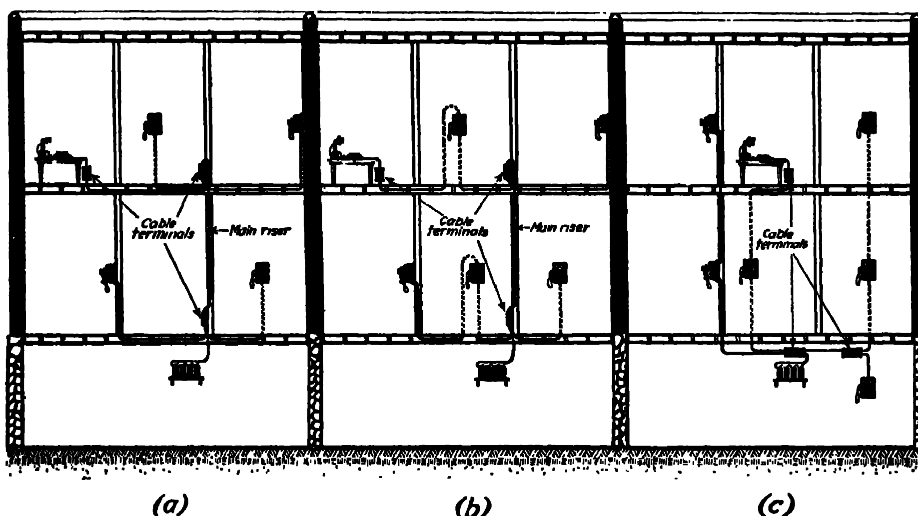


Fig. 16.

each one numbered or lettered to indicate the line it controls. Typical common battery intercommunicating sets are shown in Figs. 11, 12, and 13. An apartment house set with letter boxes is shown in Fig. 14. A person at one station wishing to talk to one of the other stations presses the corresponding button down to the ringing position, and the desired station is signalled. When this button is pushed down, any other button in the set, which might happen to be depressed, is automatically restored, thus clearing the station of any previous connection. When the pressure is removed the button comes back to a halfway or talking position, so that as soon as the called station receiver is removed the talking connections are complete.

The wiring of an intercommunicating system appears complicated, but this is due to the multiplicity of wires at each telephone. As a matter of fact, the circuits are quite simple. Diagrams of the circuits of two stations involved when one calls the other, of a Western Electric interphone system is shown in Fig. 15. The diagram shows that two sets of batteries are used, one for ringing and one for talking.

It is a good plan to use cables instead of loose wires for the inside wiring, and provision for running these cables may advantageously be made during the process of construction of the building. Methods of running interphone cables to meet different conditions are shown in Fig. 16.

SECTION 13

LIGHTNING PROTECTION

By C. M. Jansky

1. Nature of Lightning.—Lightning, as ordinarily understood, is the discharge of atmospheric electricity between clouds, or between clouds and the earth. This conception is in some respects inadequate although it does seem to state what one actually sees. A more modern conception assumed that the breaking up and recombination of water particles results in electrification of the clouds and atmosphere. This electrification produces stresses in the ether, and the lightning discharge is an equalization of these stresses. In this respect, lightning may be compared to the breaking of a piece of glass which has been rapidly chilled and thereby filled with internal stresses. When the outer surface of such a piece of glass is scratched, it suddenly breaks. The internal stresses are relieved by rupturing the glass. The breaks in the glass follow the lines of least resistance, or along the weakest lines of the glass. The influence of these internal stresses is made manifest in all parts of the glass. Similarly, a lightning discharge is a redistribution or equalization of the stresses in the ether produced by the accumulation of electricity in the clouds. This explains why an electric shock is often felt at points remote from the place of the direct stroke. The discharge sets up electromagnetic waves in the ether somewhat in the same manner as waves are set up in water when a disturbance takes place at some point in it.

The internal stresses in the suddenly chilled pieces of glass may be relieved in two different ways: one by suddenly reducing the constraining force of the envelop at one point and thus causing an explosion; and the other by reheating the glass uniformly and thus permitting the gradual equalization of the stresses. In an analogous way the equalization of the electrical stresses in the ether may be brought about by the sudden release of the forces along a non-conducting path; and the other, by a gradual readjustment or discharge along some conducting path.

The problem of lightning protection of buildings consists i[illegible]oviding conducting paths for the relatively slow and gradual dissipation of the electrification, and if the sudde[illegible]scharge cannot be avoided, to at least reduce its destructive effect to a minimum. These conducting paths cons[illegible]f copper, aluminum, or iron wire in the form of lightning rods.

Although the exact character of the lightning discharge between clouds is not known, it is quite well established that it is oscillatory when taking place through objects on the earth's surface. The lightning discharge is not a rush of electricity in one direction, but, like a steel spring when it is deflected and released, it swings past the point of equilibrium, so the lightning discharge oscillates several hundred thousand and perhaps millions of times per second. This oscillatory character of the discharge introduces certain factors in lightning rod design and installations that are usually neglected when designing conductors for low frequency electric current.

2. Electrical Conductors.—The energy of an electric current when flowing through a conductor is dissipated as heat. When the current is of low frequency, the heat is developed throughout the whole cross section of the conductor. When a high frequency alternating current passes through a conductor, the energy is converted into heat only on the outer surface of the conductor, and as electric radiations into space. The electrical resistance of a conductor is of practically no importance as far as the question of dissipating the high frequency energy of a lightning discharge is concerned. Thus from an electrical point of view, it matters little whether copper, aluminum, or iron is used for the lightning conductor. From the viewpoint of durability, the copper and aluminum take precedence.

Composite conductors—that is, conductors made of different materials—should not be used. Unless the two materials are combined in the form of an alloy—or unless, when one is used as a coating for the other, they are in intimate contact and the coating is of considerable thickness—electrolytic action will sooner or later develop,

causing rapid deterioration of the conductors. Since lightning rods are very likely to be neglected, none but the best materials and first-class workmanship should be tolerated. The form of the conductor is of little moment—it may be round, flat, solid, or stranded. It should not, however, be too small in diameter. Authorities differ with respect to the best size of wire to use, but nothing smaller than No. 2 copper, No. 00 aluminum, and No. 1 galvanized-iron wire should be used.

3. Protection Provided by Lightning Rods.—Perhaps the most extended investigations as to the effectiveness of lightning rods, were carried out under the guidance of Prof. W. H. Day of the Ontario Agricultural College. His conclusions may be briefly summarized as follows:

> Properly installed and maintained lightning rods are both a preventative of a lightning stroke and a protection against fire or serious damage in case of a lightning discharge through the rods. Experience seems to show that buildings with steel frame work, well grounded, are practically lightning proof.

4. Installation and Maintenance of Lightning Rods.—If lightning rods are not properly installed and maintained, they may prove an element of danger instead of protection; hence the following simple rules should be carefully observed:[1]

4a. Material.—If proper precautions for maintenance are taken, double galvanized-iron conductors may be used instead of copper or aluminum. No conductor smaller than No. 2 copper or No. 00 aluminum A.W.G., or No. 1 iron B.W.G. should be used. Combination wires are not advised on account of durability. The conductor may have any form that will give durability and convenience in installation.

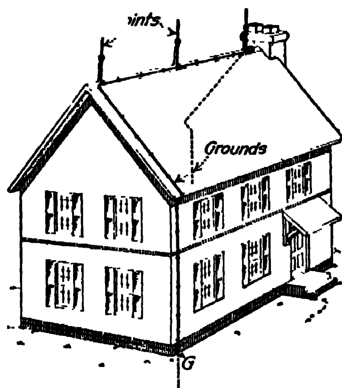


Fig. 1.

4b. Location.—The exact location and number of rods to be used in any case will depend upon the shape of the building. Two main vertical rods should be provided at each end of the building, and in addition, each tower, spire, or chimney should be protected by vertical rods (Fig. 1). Likewise short vertical rods should be erected along minor pinnacles and all should be connected by horizontal conductors. The vertical points along the ridge should be spaced not more than 20 to 30 ft., and the first should be not over 5 ft. from the end. The vertical rods need not exceed 4 to 5 ft. in height except those on or beside chimneys, cupolas, or other similar prominences; these should extend at least 18 in. above the highest point. The lical rods should be of the same material as the horizontal conductors.

·. Grounding.—Grounding is one of the most important features of installation. Unless the grounding is effective, the rods may do more harm than good. The first essential of a good ground is to extend the conductors to a depth sufficient to ensure contact with permanent moist earth, hence proximity to rain water pipes and to drains is desirable. The exact depth will depend upon local conditions but the conductor should extend at least 8 ft. below the surface. It is a very good plan to make the conductor divide close below the surface of the ground and adopt either of two methods for securing the escape of the lightning into the earth. A strip of copper tape may be led from the bottom of the rod to the nearest water main, not merely to a lead pipe, and be soldered to it; or a tape may be soldered to a sheet of copper 3 × 3 ft. at least 1/16 in. thick, buried in permanently wet earth, and surrounded by cinders or coke. Where iron is used for the rod, a galvanized iron plate of similar dimensions should be employed. Instead of the plate, there are advantages of using a tubular earth connection consisting of a perforated steel pipe driven tightly into moist ground and lengthened up to the surface. A conductor reaching to the bottom and packed with granulated charcoal, is as effective an area as a plate of larger surface, and can easily be kept moist by connecting it with the nearest

[1] Lightning Rods, Bul. No. 220. Ontario Agricultural College.
Lightning and Lightning Conductors, Farmers' Bul. No. 367, U. S. Dept. of Agriculture.
Lightning Rods, E. J. Berg, Standard Handbook for Electrical Engineers.

drain water pipe. To prevent injury, the grounding cables should be protected to a height of 6 to 8 ft. above the ground by nailing boards around them.

4d. Construction.—All roof metals, such as finials, ridging, rain-water and ventilating pipes, metal bowls, lead flashing, gutters, etc., should be well grounded. Some recommend that these metal portions be connected to the conductors; others, like Sir Oliver Lodge, suggest that it is advisable to connect these metal parts together and then ground them rather than connect them to the conductor, as this introduces an element of danger.

All large masses of metal in the building should be connected to earth, either directly or by means of a lower horizontal conductor.

Where roofs are partially or wholly metal lined, they should be connected to earth by means of vertical rods at several points, preferably at the lower corners, never from the ridge. Gas pipes should be kept as far away as possible from the positions occupied by lightning conductors, and, as an additional protection, the service mains to the gas meter should be metallically connected with house services leading from the meter.

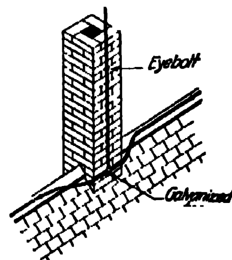


Fig. 2.

All lightning conductors should be metallically connected with the building. The fastenings whether nails, staples, or clips should preferably be of the same material as the conductor. A good method of fastening a galvanized iron rod to a chimney is shown in Fig. 2. Where the conductors change direction, all sharp bends should be avoided.

4e. Maintenance.—If galvanized-iron conductors and rods are used, the whole system should receive two coats of aluminum paint, and the painting should be repeated every few years. The system should likewise be regularly inspected, especially after a heavy wind storm or in the spring after a severe winter.

APPENDIX A

GENERAL NOTATION

For all materials except reinforced concrete:

f = unit fiber stress.
v = unit shearing stress (horizontal or vertical).
V = total shear.
c = distance from neutral axis to extreme fiber.
b = breadth of rectangular section.
d = depth of section.
A = area of section.
I = moment of inertia.
r = radius of gyration.
S = section modulus.
M = bending moment or resisting moment.
l = span or length.
L = span or length.
F or P = concentrated load or total stress in a member.
w = uniformly distributed load per unit of length.
W = total uniformly distributed load.
R = reactions at supports or resultant of forces
E = modulus of elasticity.
Δ = total deformation or maximum deflection of beams.
δ = unit deformation.
e = eccentricity.

For reinforced concrete:

(*a*) Rectangular Beams

f_s = tensile unit stress in steel.
f_c = compressive unit stress in concrete.
f_c' = ultimate compressive unit stress in concrete.
E_s = modulus of elasticity of steel.
E_c = modulus of elasticity of concrete.
$n = \frac{E_s}{E_c}$.
M = moment of resistance, or bending moment in general.
A_s = steel area.
b = breadth of beam.
d = depth of beam to center of steel
k = ratio of depth of neutral axis to depth, d.
z = depth below top to resultant of the compressive stresses.
j = ratio of lever arm of resisting couple to depth, d.
$jd = d - z$ = arm of resisting couple.
p = steel ratio $= \frac{A_s}{bd}$.

(*b*) T-beams

b = width of flange.
b' = width of stem.
t = thickness of flange.

(*c*) Beams Reinforced for Compression

A' = area of compressive steel.
p' = steel ratio for compressive steel.
f_s' = compressive unit stress in steel.
C = total compressive stress in concrete.
C' = total compressive stress in steel.
d' = depth of center of compressive steel.
r = depth to resultant of C and C'.

(*d*) Shear, Bond and Web Reinforcement

V = total shear.
V' = total shear producing stress in reinforcement.
v = shearing unit stress.
u = bond stress per unit area of bar.
o = circumference or perimeter of bar
Σo = sum of the perimeters of all bars
T = total stress in single reinforcing member.
s = horizontal spacing of reinforcing members.

(*e*) Columns

A = total net area.
A_s = area of longitudinal steel.
A_c = area of concrete.
P = total safe load.

APPENDIX B

SPECIFICATIONS FOR PORTLAND CEMENT

(American Society for Testing Materials)
(Serial Designation: C9-26)

1. **Definition.**—Portland cement is the product obtained by finely pulverizing clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

I. Chemical Properties

2. **Chemical Limits.**—The following limits shall not be exceeded:

	Per cent
Loss on ignition	4.00
Insoluble residue	0.85
Sulphuric anhydride (SO_3)	2.00
Magnesia (MgO)	5.00

II. Physical Properties

3. **Fineness.**—The residue on a standard No. 200 sieve shall not exceed 22 % by weight.

4. **Soundness.**—A pat of neat cement shall remain firm and hard and sh[illegible] signs of distortion, cracking, checking, or disintegration in the steam test for soundness.

5. **Time of Setting.**—The cement shall not develop initial set in less than 45 min. when the Vicat needle is used or 60 min. when the Gillmore needle is used. Final set shall be attained within 10 hr.

6. **Tensile Strength.**—The average tensile strength in pounds per square inch of not less than three standard mortar briquets (see Section 47) composed of 1 part of cement and 3 parts of standard sand, by weight, shall be equal to or higher than the following:

Age at test, days	Storage of briquets		Tensile strength, pounds per square inch
	Number of days in moist air	Number of days in water	
7	1	6	225
28	1	27	325

7. The average tensile strength of standard mortar at 28 days shall be higher than the strength at 7 days.

III. Packing, Marking, and Storage

8. **Packages and Marking.**—The cement shall be delivered in packages as specified, with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. When shipped in bulk, this information shall be contained in the shipping advices accompanying the shipment. A bag shall contain 94 lb. net. A barrel shall contain 376 lb. net. All packages shall be in good condition at the time of inspection.

9. **Storage.**—The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment and in a suitable weather-tight building which will protect the cement from dampness.

IV. Inspection

10. **Inspection.**—Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or the site of the work, as may be specified by the purchaser. At least 12 days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 33 days shall be allowed for the completion of the 28-day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The 28-day test need not be made if waived by the purchaser.

V. Rejection

11. **Rejection.**—The cement may be rejected if it fails to meet any of the requirements of these specifications.

12. Cement remaining in storage prior to shipment for a period greater than 6 mo. after test shall be retested and shall be rejected if it fails to meet any of the requirements of these specifications.

13. Cement shall not be rejected on account of failure to meet the fineness requirement, if, upon re-test, after drying at 100 deg. C. for 1 hour, it meets this requirement.

14. Cement failing to meet the test for soundness in steam may be accepted if it passes a re-test using a new sample at any time within 28 days thereafter. The provisional acceptance of the cement at the mill shall not deprive the purchaser of the right of rejection on a re-test of soundness and time of setting at the time of delivery of cement to the purchaser.

15. Packages varying more than 5 % from the specified weight may be rejected; and if the average weight of packages in any shipment, as shown by weighing 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

APPENDIX C

SPECIFICATIONS FOR STRUCTURAL STEEL FOR BUILDINGS

(American Society for Testing Materials)
(Serial Designation: A9-24)

I. Manufacture

1. **Process.**—(*a*) Structural steel, except as noted in paragraph (*b*), shall be made by either or both of the following processes: bessemer or open-hearth.

(*b*) Rivet steel, and steel for plates or angles over ¾ in. in thickness which are to be punched, shall be made by the open-hearth process.

II. Chemical Properties and Tests

2. **Chemical Composition.**—The steel shall conform to the following requirements as to chemical composition:

		Structural steel, per cent	Rivet steel, per cent
Phosphorus	bessemer	Not over 0.10	Not over 0.06
	open-hearth	Not over 0.06	
Sulphur		....	Not over 0.045

3. **Ladle Analyses.**—(*a*) A carbon determination shall be made of each melt of bessemer steel, and determinations for manganese, phosphorus, and sulphur representing the average of the melts applied for each 12-hour period.

(*b*) An analysis of each melt of open-hearth steel shall be made for carbon, manganese, phosphorus, and sulphur.

(*c*) These analyses shall be made by the manufacturer from test ingots taken during the pouring of each melt. The chemical composition thus determined shall be reported to the purchaser or his representative and shall conform to the requirements specified in Section 2.

4. **Check Analyses.**—Analyses may be made by the purchaser from finished material representing each melt. The phosphorus and sulphur content thus determined shall not exceed that specified in Section 2 by more than 25 %.

III. Physical Properties and Tests

5. **Tension Tests.**—(*a*) The material shall conform to the following requirements as to tensile properties:

Properties considered	Structural steel	Rivet steel
Tensile strength, pounds per square inch	55,000–65,000	46,000–55,000
Yield point, minutes per square inch	0.5 tensile strength	0.5 tensile strength
but in no case less than	33,000	25,000
Elongation in 8 inches, minutes, per cent	$\frac{1,400,000^*}{\text{Tensile strength}}$	$\frac{1,400,000}{\text{Tensile strength}}$
Elongation in 2 inches, minutes, per cent	22	

* See Section 6.

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

6. **Modifications in Elongation.**—(*a*) For structural steel over ¾ in. in thickness, a deduction from the percentage of elongation in 8 in. specified in Section 5(*a*) of 0.25 % shall be made for each increase of 1/32 in. of the specified thickness above ¾ in., to a minimum of 18 %.

(*b*) For structural steel under 5/16 in. in thickness, a deduction from the percentage of elongation in 8 in. specified in Section 5(*a*) of 1.25 % shall be made for each decrease of 1/32 in. of the specified thickness below 5/16 in.

7. **Bend Tests.**—(*a*) Bend-test specimens, except as specified in paragraph (*b*), shall stand being bent cold through 180 deg. without cracking on the outside of the bent portion, as follows: for material ¾ in. or under in thickness, flat on itself; for material over ¾ in. to and including 1¼ in. in thickness, around a pin the diameter of which is equal to the thickness of the specimen; and for material over 1¼ in. in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen.

(*b*) Bend-test specimens for rivet steel shall stand being bent cold through 180 deg. flat on themselves without cracking on the outside of the bent portion.

8. **Test Specimens.**—(*a*) Test specimens shall be prepared for testing from the material in its rolled or forged condition, except as specified in paragraphs (*b*) and (*c*).

(*b*) Test specimens for annealed material shall be prepared from the material as annealed for use or from a short length of a full section similarly treated.

(*c*) Test specimens for rivet bars which have been cold drawn shall be normalized before testing.

(*d*) Test specimens shall be taken longitudinally and, except as specified in paragraphs (*f*), (*g*), and (*h*), shall be of the full thickness or section of material as rolled.

(*e*) Test specimens for plates, shapes, and flats may be machined to form and dimensions shown in Fig. 1, or with both edges parallel.

(*f*) Tension-test specimens for material over 1½ in. in thickness or diameter, except pins and rollers, may be machined to a thickness or diameter of at least ¾ in. for a length of at least 9 in., or they may conform to the dimensions shown in Fig. 2.

(*g*) Bend-test specimens for material over 1½ in. in thickness or diameter, except pins and rollers, may be machined to a thickness or diameter of at least ¾ in. or to 1 × ½ in. in section.

(*h*) Tension-test specimens for pins and rollers shall conform to the dimensions shown in Fig. 2, and bend-test specimens shall be 1 × ½ in. in section.

(*i*) Test specimens for pins and rollers shall be taken so that the axis is 1 in from the surface.

(*j*) The machined sides of rectangular bend-test specimens may have the corners rounded to a radius not over

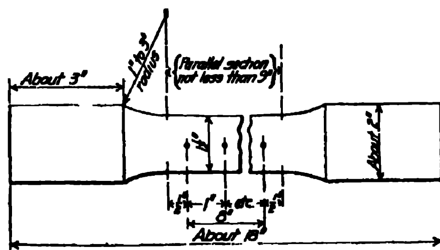
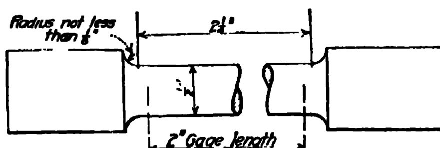


Fig. 1.



Note:—The gage length, parallel portions and fillets shall be as shown, but the ends may be of any form which will fit the holders of the testing machine.

Fig. 2.

9. **Number of Tests.**—(*a*) One tension and one bend test shall be made from each melt; except that if material from one melt differs ⅜ in. or more in thickness, one tension and one bend test shall be made from both the thickest and the thinnest material rolled.

(*b*) If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

(*c*) If the percentage of elongation of any tension-test specimen is less than that specified in Section 5 (*a*) and any part of the fracture is more than ¾ in. from the center of the gage length of a 2-in. specimen or is outside the middle third of the gage length of an 8-in. specimen, as indicated by scribe scratches marked on the specimen before testing, a re-test shall be allowed.

IV. Permissible Variations in Weights and Thickness

10. **Permissible Variations.**—The cross section or weight of each piece of steel shall not vary more than 2.5% from that specified; except in the case of sheared plates, which shall be covered by the following permissible variations. One cubic inch of rolled steel is assumed to weigh 0.2833 lb.

(*a*) *When Ordered to Weight per Square Foot:* The weight of each lot[1] in each shipment shall not vary from the

[1] The term "lot" applied to Table I means all the plates of each group width and group weight.

weight ordered more than the amount given in Table I.

(*b*) *When Ordered to Thickness:* The thickness of each plate shall not vary more than 0.01 in. under that ordered. The overweight of each lot[1] in each shipment shall not exceed the amount given in Table II.

[1] The term "lot" applied to Table II means all the plates of each group width and group thickness.

V. Finish

11. **Finish.**—The finished material shall be free from injurious defects and shall have a workmanlike finish.

VI. Marking

12. **Marking.**—The name or brand of the manufacturer and the melt number shall be legibly stamped or rolled on all finished material, except that rivet and lattice bars and other small sections shall, when loaded for shipment, be properly separated and marked for identification. The identification marks shall be legibly stamped on the end of each pin and roller. The melt number shall be legibly marked, by stamping if practicable, on each test specimen.

VII. Inspection and Rejection

13. **Inspection.**—The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturers' works which concern the manufac-

ture of the material ordered. The manufacturer shall afford the inspector, without charge, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

14. Rejection.—(*a*) Unless otherwise specified, any rejection based on tests made in accordance with Section 4 shall be reported within five working days from the receipt of samples.

(*b*) Material which shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

15. Re-hearing.—Samples tested in accordance with Section 4, which represent rejected material, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

TABLE I.—PERMISSIBLE VARIATIONS OF RECTANGULAR PLATES ORDERED TO WEIGHT

Permissible variations in average weights per square foot of plates for widths given, expressed in percentages of ordered weights

Ordered weight (lb. per sq. ft.)	Under 48 in. Over	Under 48 in. Under	48 to 60 in., excl. Over	48 to 60 in., excl. Under	60 to 72 in., excl. Over	60 to 72 in., excl. Under	72 to 84 in., excl. Over	72 to 84 in., excl. Under	84 to 96 in., excl. Over	84 to 96 in., excl. Under	96 to 108 in., excl. Over	96 to 108 in., excl. Under	108 to 120 in., excl. Over	108 to 120 in., excl. Under	120 to 132 in., excl. Over	120 to 132 in., excl. Under	132 in. or over Over	132 in. or over Under	Ordered weight (lb per sq. ft.)
Under 5..........	5.0	3.0	5.5	3.0	6.0	3.0	7.0	3.0	...	...	...	...	...	...	...	...	...	...	Under 5
5 to 7.5 excl......	4.5	3.0	5.0	3.0	5.5	3.0	6.0	3.0	...	...	...	...	...	...	...	...	...	...	5 to 7.5 excl.
7.5 to 10 excl.....	4.0	3.0	4.5	3.0	5.0	3.0	5.5	3.0	6.0	3.0	7.0	3.0	8.0	3.0	...	...	...	...	7.5 to 10 excl.
10 to 12.5 excl....	3.5	2.5	4.0	3.0	4.5	3.0	5.0	3.0	5.5	3.0	6.0	3.0	7.0	3.0	8.0	3	9.0	3	10 to 12.5 excl.
12.5 to 15 excl....	3.0	2.5	3.5	2.5	4.0	3.0	4.5	3.0	5.0	3.0	5.5	3.0	6.0	3.0	7.0	3	8.0	3	12.5 to 15 excl.
15 to 17.5 excl....	2.5	2.5	3.0	2.5	3.5	2.5	4.0	3.0	4.5	3.0	5.0	3.0	5.5	3.0	6.0	3	7.0	3	15 to 17.5 excl.
17.5 to 20 excl....	2.5	2.0	2.5	2.5	3.0	2.5	3.5	2.5	4.0	3.0	4.5	3.0	5.0	3.0	5.5	3	6.0	3	17.5 to 20 excl
20 to 25 excl......	2.0	2.0	2.5	2.0	2.5	2.5	3.0	2.5	3.5	2.5	4.0	3.0	4.5	3.0	5.0	3	5.5	3	20 to 25 excl.
25 to 30 excl......	2.0	2.0	2.0	2.0	2.5	2.0	2.5	2.5	3.0	2.5	3.5	3.0	4.0	3.0	4.5	3	5.0	3	25 to 30 excl.
30 to 40 excl......	2.0	2.0	2.0	2.0	2.0	2.0	2.5	2.0	2.5	2.5	3.0	2.5	3.5	3.0	4.0	3	4.5	3	30 to 40 excl.
40 or over........	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5	2.0	2.5	2.5	3.0	2.5	3.5	3	4.0	3	40 or over.

NOTE.—The weight per square foot of individual plates shall not vary from the ordered weight by more than 1⅓ times the amount given in this table.

TABLE II.—PERMISSIBLE OVERWEIGHTS OF RECTANGULAR PLATES ORDERED TO THICKNESS

Permissible excess in average weights per square foot of plates for widths given, expressed in percentages of nominal weights

Ordered thickness (inches)	Under 48 in.	48 to 60 in., excl.	60 to 72 in., excl.	72 to 84 in., excl.	84 to 96 in., excl.	96 to 108 in., excl.	108 to 120 in., excl.	120 to 132 in., excl.	132 in. or over	Ordered thickness (inches)
Under ⅛...........	9.0	10.0	12.0	11.0	....	....	..	..	..	Under ⅛
⅛ to 3/16 excl.......	8.0	9.0	10.0	12.0	....	..	..	..	..	⅛ to 3/16 excl.
3/16 to ¼ excl.......	7.0	8.0	9.0	10.0	12.0	..	..	..	..	3/16 to ¼ excl.
¼ to 5/16 excl.......	6.0	7.0	8.0	9.0	10.0	12.0	14	16	19	¼ to 5/16 excl.
5/16 to ⅜ excl.......	5.0	6.0	7.0	8.0	9.0	10.0	12	14	17	5/16 to ⅜ excl.
⅜ to 7/16 excl.......	4.5	5.0	6.0	7.0	8.0	9.0	10	12	15	⅜ to 7/16 excl.
7/16 to ½ excl.......	4.0	4.5	5.0	6.0	7.0	8.0	9	10	13	7/16 to ½ excl.
½ to ⅝ excl.........	3.5	4.0	4.0	5.0	6.0	7.0	8	9	11	½ to ⅝ excl.
⅝ to ¾ excl.........	3.0	3.5	4.0	4.5	5.0	6.0	7	8	9	⅝ to ¾ excl.
¾ to 1 excl.........	2.5	3.0	3.5	4.0	4.5	5.0	6	7	8	¾ to 1 excl.
1 or over............	2.5	2.5	3.0	3.5	4.0	4.5	5	6	7	1 or over

APPENDIX D

SPECIFICATIONS FOR CONCRETE REINFORCEMENT

SPECIFICATIONS FOR BILLET-STEEL CONCRETE REINFORCEMENT BARS

(American Society for Testing Materials)
(Serial Designation: A15-14)

1. **Material Covered.**—(*a*) These specifications cover three classes of billet-steel concrete reinforcement bars, namely: plain, deformed, and cold twisted.

(*b*) Plain and deformed bars are of three grades, namely; structural-steel, intermediate, and hard.

2. **Basis of Purchase.**—(*a*) The structural-steel grade shall be used unless otherwise specified.

(*b*) If desired, cold-twisted bars may be purchased on the basis of tests of the hot-rolled bars before twisting in which case such tests shall govern and shall conform to the requirements specified for plain bars of structural steel grade.

3. **Manufacture.**—(*a*) The steel may be made by the bessemer or open-hearth process.

(*b*) The bars shall be rolled from new billets. No re-rolled material will be accepted.

4. Cold-twisted bars shall be twisted cold with one complete twist in a length not over 12 times the thickness of the bar.

5. **Chemical Properties and Tests.**—The steel shall conform to the following requirements as to chemical composition:

	Per cent
Phosphorus, bessemer	not over 0.10
Open-hearth	not over 0.05

6. An analysis of each melt of steel shall be made by the manufacturer to determine the percentages of carbon, manganese, phosphorus and sulphur. This analysis shall be made from a test ingot taken during the pouring of the melt. The chemical composition thus determined shall be reported to the purchaser or his representative, and shall conform to the requirements specified in Section 5.

7. Analyses may be made by the purchaser from finished bars representing each melt of open-hearth steel, and each melt, or lot of 10 tons, of bessemer steel. The phosphorus content thus determined shall not exceed that specified in Section 5 by more than 25%.

8. **Physical Properties and Tests.**—(*a*) The bars shall conform to the following requirements as to tensile properties:

Properties considered	Plain bars			Deformed bars			Cold-twisted bars
	Structural-steel grade	Intermediate grade	Hard grade	Structural-steel grade	Intermediate grade	Hard grade	
Tensile strength, lb. per sq. in.	55,000 to 70,000	70,000 to 85,000	80,000 min.	55,000 to 70,000	70,000 to 85,000	80,000 min.	Recorded only
Yield point, min., lb. per sq. in.	33,000	40,000	50,000	33,000	40,000	50,000	55,000
Elongation in 8 in. min. %[1]	1,400,000 / Tens. str.	1,300,000 / Tens. str.	1,200,000 / Tens. str.	1,250,000 / Tens. str.	1,125,000 / Tens. str.	1,000,000 / Tens. str.	5

[1] See Section 9.

(b) The yield point shall be determined by the drop of the beam of the testing machine.

9. (a) For plain and deformed bars over 3/4 in. in thickness or diameter, a deduction of 1 from the percentages of elongation specified in Section 8(a) shall be made for each increase of 1/8 in. in thickness or diameter above 3/4 in.

(b) For plain and deformed bars under 7/16 in. in thickness or diameter, a deduction of 1 from the percentages of elongation specified in Section 8(a) shall be made for each decrease of 1/16 in. in thickness or diameter below 7/16 in.

10. The test specimen shall bend cold around a pin without cracking on the outside of the bent portion, as follows:

Thickness or diameter of bar	Plain bars			Deformed bars			Cold-twisted bars
	Structural-steel grade	Intermediate grade	Hard grade	Structural-steel grade	Intermediate grade	Hard grade	
Under 3/4 in.	180 deg. $d = t$	180 deg. $d = 2t$	180 deg. $d = 3t$	180 deg. $d = t$	180 deg. $d = 3t$	180 deg. $d = 4t$	180 deg. $d = 2t$
3/4 in. or over	180 deg. $d = t$	90 deg. $d = 2t$	90 deg. $d = 3t$	180 deg. $d = 2t$	90 deg. $d = 3t$	90 deg. $d = 4t$	180 deg. $d = 3t$

d = diameter of pin about which the specimen is bent.
t = thickness or diameter of specimen.

11. (a) Tension and bend test specimens for plain and deformed bars shall be taken from the finished bars and shall be of the full thickness or diameter of bars as rolled; except that the specimens for deformed bars may be machined for a length of at least 9 in., if deemed necessary by the manufacturer to obtain uniform cross-section.

(b) Tension and bend test specimens for cold-twisted bars shall be taken from the finished bars, without further treatment; except as specified in Section 2(b).

12. (a) One tension and one bend test shall be made from each melt of open-hearth steel, and from each melt, or lot of 10 tons, of bessemer steel; except that if material from one melt differs 3/8 in. or more in thickness or diameter, one tension and one bend shall be made from both the thickest and the thinnest material rolled.

(b) If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

(c) If the percentage of elongation of any tension test specimen is less than that specified in Section 8(a) and any part of the fracture is outside the middle third of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

13. *Permissible Variations in Weight.*—The weight of any lot of bars shall not vary more than 5% from the theoretical weight of that lot.

14. **Finish.**—The finished bars shall be free from injurious defects and shall have a workmanlike finish.

15. **Inspection and Rejection.**—The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the bars ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the bars are being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

16. (a) Unless otherwise specified, any rejection based on tests made in accordance with Section 7 shall be reported within 5 working days from the receipt of the samples.

(b) Bars which show injurious defects subsequent to their acceptance at the manufacturer's works shall be rejected, and the manufacturer shall be notified.

17. Samples tested in accordance with Section 7, which represent rejected bars, shall be preserved for 2 weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

STANDARD SPECIFICATIONS FOR RAIL-STEEL CONCRETE REINFORCEMENT BARS

(American Society for Testing Materials)

(Serial Designation: A16-14)

1. The specifications cover three classes of rail-steel concrete reinforcement bars, namely: plain, deformed, and hot-twisted.

2. **Manufacture.**—The bars shall be rolled from standard section T-rails.

3. Hot-twisted bars shall have one complete twist in a length not over 12 times the thickness of the bar.

Properties considered	Plain bars	Deformed and hot-twisted bars
Tensile strength, lb. per sq. in	80,000	80,000
Yield point, lb. per sq. in	50,000	50,000
Elongation in 8 in., %[1]	1,200,000 / Tens. str.	1,000,000 / Tens. str.

[1] See Sectio

4. **Physical Properties and Tests.**- -(a) The bars shall conform to the followi nimum requirements as to tensile properties:

(b) The yield point shall be determined by the drop of the beam of the testing machine.

5. (a) For bars over ¾ in. in thickness or diameter, a deduction of 1 from the percentages of elongation specified in Section 4 (a) shall be made for each increase of ⅛ in. in thickness or diameter above ¾ in.

(b) For bars under 7⁄16 in. in thickness or diameter, a deduction of 1 from the percentages of elongation specified in Section 4(a) shall be made for each decrease of 1⁄16 in. in thickness or diameter below 7⁄16 in.

6. The test specimen shall bend cold around a pin without cracking on the outside of the bent portion, as follows:

Thickness of diameter of bar	Plain bars	Deformed and hot-twisted bars
Under ¾ in.	180 deg. $d = 3t$	180 deg. $d = 4t$
¾ in. or over	90 deg. $d = 3t$	90 deg. $d = 4t$

7. (a) Tension and bend test specimens for plain and deformed bars shall be taken from the finished bars, and shall be of the full thickness or diameter of bars as rolled; except that the specimens for deformed bars may be machined for a length of at least 9 in., if deemed necessary by the manufacturer to obtain uniform cross section.

(b) Tension and bend test specimens for hot-twisted bars shall be taken from the finished bars, without further treatment.

8. (a) One tension and one bend test shall be made from each lot of 10 tons or less of each size of bar rolled from rails varying not more than 10 lb. per yd. in nominal weight.

(b) If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

(c) If the percentage of elongation of any tension test specimen is less than that specified in Section 4(a) and any part of the fracture is outside the middle third of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

9. **Permissible Variations in Weight.**—The weight of any lot of bars shall not vary more than 5% from the theoretical weight of that lot.

10. **Finish.**—The finished bars shall be free from injurious defects and shall have a workmanlike finish.

11. **Inspection and Rejection.**—The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the bars ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the bars are being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

12. Bars which show injurious defects subsequent to their acceptance at the manufacturer's works will be ejected, and the manufacturer shall be notified.

TENTATIVE SPECIFICATIONS FOR COLD-DRAWN STEEL-WIRE REINFORCEMENT

(American Society for Testing Materials)

(Serial Designation: A82-21 T)

1. **Material Covered.**—These specifications cover cold-drawn steel wire to be used as such, or in fabricated form, for the reinforcement of concrete, in gages not less than 0.080 in. nor greater than 0.500 in.

2. **Basis of Purchase.**—When wire is ordered by gage number, the following relation between number and diameter, in inches, shall apply unless otherwise specified:

Gage number	Equivalent diameter, inches	Gage number	Equivalent diameter, inches
0,000,000	0.4900	5	0.2070
000,000	0.4615	6	0.1920
00,000	0.4305	7	0.1770
0,000	0.3938	8	0.1620
000	0.3625	9	0.1483
00	0.3310	10	0.1350
0	0.3065	11	0.1205
1	0.2830	12	0.1055
2	0.2625	13	0.0915
3	0.2437	14	0.0800
4	0.2253		

I. Manufacture

3. **Process.**—(*a*) The steel shall be made by either or both of the following processes: bessemer or open hearth.

(*b*) *Drawing.*—The wire shall be cold drawn from rods hot rolled from billets.

II. Physical Properties and Tests

4. **Tension Tests.**—(*a*) The wire, except as specified in paragraphs (*b*) and (*c*), shall conform to the following minimum requirements as to tensile properties·

Tensile strength	80,000 lb. per sq. in.
Reduction of area	30 %

(*b*) For wire to be used in the fabrication of mesh, a minimum tensile strength of 70,000 lb. per sq. in. shall be permitted.

(*c*) For wire testing over 100,000-lb.-per-sq.-in. tensile strength, the reduction of area shall be not less than 25 %.

5. **Bend Tests.**— The test specimen shall withstand being bent cold through 180 deg. without cracking on the outside of the bent portion.

For wire 0.3 in diameter or under, around a pin the diameter of which is equal to the diameter of the specimen.

For wire over 0.3 in. in diameter or under, around a pin the diameter of which is equal to twice the diameter of the specimen.

6. **Test Specimens.**—Tension, and bend-test specimens shall be of the full-size section of the wire as drawn.

7. (*a*) One tension and one bend test shall be made for each 10 tons or less or each size of wire.

(*b*) If any test specimen shows defects or develops flaws, it may be discarded and another specimen substituted.

III. Permissible Variations in Gage

8. The diameter of the wire shall not vary more than 0.003 in. from the size ordered.

IV. Finish

9. **Finish.**- -The finished wire shall be free from injurious defects and shall have a workmanlike finish, with smooth surface.

V. Inspection and Rejection

10. **Inspection.**— The manufacturer shall afford the inspector, without charge, all reasonable facilities to satisfy him that the wire is being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

11. **Rejection.** —Wire which shows injurious defects subsequent to its acceptance at the manufacturer's works shall be rejected, and the manufacturer notified.

APPENDIX E

SPECIFICATIONS FOR CONCRETE BUILDING BLOCK, TILE AND BRICK

AMERICAN CONCRETE INSTITUTE TENTATIVE SPECIFICATIONS FOR CONCRETE BUILDING BLOCK AND CONCRETE BUILDING TILE

(Serial Designation: P-1-A28T)

I. General

1. The purpose of these specifications is to define the requirements for concrete building block and concrete building tile to be used in construction.

2. The word "concrete" shall be understood to mean Portland cement concrete.

3. **Strength Requirements.**—The average compressive strength of three or more concrete block or concrete building tile in lb. per sq. in. of gross cross-sectional area as laid in the wall shall not be less than 700 lb., no one unit falling below 600 lb. 28 days after being manufactured or when shipped.

Wherever block or building tile are used to carry unusual heavy loads, the average compressive strength of three or more of these units 28 days after being manufactured or when shipped in lb. per sq. in. of gross cross-sectional area as laid in the wall shall be at least ten times the figured superimposed load to be applied.

Non-load-bearing concrete block and concrete tile shall have sufficient strength necessary to prevent excessive breakage during delivery and handling.

4. The gross cross-sectional area of a one-piece concrete block or tile shall be considered as the product of the length times the width of the unit as laid in the wall. No allowance shall be made for air spaces in hollow units. The gross cross-sectional area of each unit of a two-piece block or tile shall be considered the product of the length of the unit times one-half the thickness of the wall for which the two-piece block or tile is intended.

5. The compressive strength of the concrete in units of all classifications except non-load-bearing block shall be at least 1000 lb. per sq. in., when calculated on the minimum cross-sectional area in bearing.

6. **Absorption Requirements.**—Concrete building block and tile to be exposed to soil or weather in the finished work (without stucco, plaster, or other suitable protective covering) shall meet the requirements of the absorption test.

7. All concrete building block and tile not covered by paragraph 6 need not meet an absorption requirement.

8. Concrete block and tile shall not absorb more than 10 % of the dry weight of the unit when tested as hereinafter specified, except when it is made of concrete weighing less than 140 lb. per cu. ft. For block or tile made with concrete weighing less than 140 lb. per cu. ft. the absorption in per cent by weight shall not be more than 10 multiplied by 140 and divided by the unit weight in pounds per cubic foot of the concrete under consideration.

9. **Sampling.**—Specimens for tests shall be representative of the commercial product of the plant.

10. Not less than three and preferably five specimens shall be required for each test.

11. The specimens used in the absorption test may be used for the strength test.

II. Methods of Testing

12. **Absorption Test.**—The specimens shall be immersed in clean water at approximately 70 deg. F. for a period of 24 hours. They shall then be removed, the surface water wiped off, and the specimens weighed. Specimens shall be dried to a constant weight at a temperature of from 212 to 250 deg. F. and re-weighed. Absorption is the difference in weight divided by the weight of the dry specimens and multiplied by 100.

13. **Weight of Concrete.**—The weight per cubic foot of the concrete in a block or tile is the weight of the unit in pounds divided by its volume in cubic feet. To obtain the volume of the unit, fill a vessel with enough water to immerse the specimen. The greatest accuracy will be obtained with the smallest vessel in which the specimen can be immersed with its length vertical. Mark the level of the water, then immerse the saturated specimen and weigh the vessel. Draw the water down to its original level and weigh the vessel again. The difference between the two weights divided by 62.5 equals the volume of the specimen in cubic feet.

14. **Strength Test.**—Specimens for the strength test shall be dried to constant weight at a temperature of from 212 to 250 deg. F.

15. The specimens to be tested shall be carefully measured for overall dimensions of length, width, and height.

16. Bearing surfaces shall be made plane by capping with plaster of Paris or a mixture of one-half Portland cement and one-half Plaster of Paris, which shall be allowed thoroughly to harden (from 3 to 6 hours) before the test. No point on the surface shall deviate from the plane more than 0.003 in. The cap shall not be thicker than ⅛ in. It shall be formed by means of an accurately machined metal plate or a heavy plate glass having a true surface.

17. Specimens shall be accurately centered in the testing machine.

18. The load shall be applied through a spherical bearing block placed on top of the specimen. The rate of loading after 50 % of the ultimate load has been applied shall not be greater than that which will produce a shortening of the specimen of 0.02 in. per min.

19. When testing other than rectangular block or tile, care must be taken to see that the load is applied through the center of gravity of the specimen.

20. Machined-steel or cast-iron plates of sufficient thickness to prevent apprecial e bending shall be placed between the spherical bearing block and the specimen. In no case shall the distance between the edge of the spherical bearing block and the end of the bearing plate be greater than twice the thickness of the plate. Where a number of thin plates are used, in no case shall the plates be less than 1 in thick, nor shall any plate extend beyond the one immediately above it a greater distance than twice the thickness of the plate.

21. The specimen shall be loaded to failure.

22. The compressive strength in pounds per square inch of gross cross-sectional area is the total applied load in pounds divided by the gross cross-sectional area in square inches.

AMERICAN CONCRETE INSTITUTE TENTATIVE SPECIFICATIONS FOR CONCRETE BRICK

(Serial Designation: P-1-B26T)

I. General

1. The purpose of these specifications is to define the requirements for concrete brick to be used in construction.

2. The word "concrete" shall be understood to mean Portland cement concrete.

3. The average compressive strength of concrete brick 28 days after being manufactured or when shipped shall not be less than 1500 lb. per sq. in. of gross cross-sectional area as laid in the wall, and the compressive strength of any individual brick shall be not less than 1000 lb. per sq. in. of gross cross-sectional area as laid in the wall.

4. The gross cross-sectional area of a brick shall be considered as the product of the length times the width of the unit as laid in the wall.

5. Concrete brick shall not absorb more than 12 % of the dry weight of the brick when tested, as hereinafter specified, except when they are made of concrete weighing less than 125 lb. per cu. ft. For brick made of concrete weighing less than 125 lb. per cu. ft., the average absorption in percentage by weight shall not be more than 12 multiplied by 125 and divided by the unit weight in pounds per cubic feet of the concrete under consideration.

6. Specimens for tests shall be representative of the commercial product of the plant.

7. Five specimens shall be required for each test.

8. The specimens used in the absorption test may be used for the strength test.

II. Methods of Testing

9. **Absorption Test.**—The specimens shall be immersed in clean water at approximately 70 deg. F. for a period of 24 hours. They shall then be removed, the surface water wiped off, and the specimens weighed. Specimens shall be dried to a constant weight at a temperature of from 212 to 250 deg. F. and re-weighed. Absorption is the difference in weight divided by the weight of the dry specimens and multiplied by 100.

10. **Strength Test.**—Specimens for the strength test shall be dried to constant weight at a temperature of from 212 to 250 deg. F.

11. The specimens to be tested shall be carefully measured for overall dimensions of length, width, and thickness.

12. Bearing surfaces shall be made plane by capping with plaster of Paris or a mixture of Portland cement and plaster which shall be allowed to harden thoroughly before the test.

13. Specimens shall be accurately centered in the testing machine.

14. The load shall be applied through a spherical bearing block placed on top of the specimen.

15. Metal plates of sufficient thickness to prevent appreciable bending shall be placed between the spherical bearing block and the specimen.

16. The specimen shall be loaded to failure.

17. The compressive strength in pounds per square inch of gross cross-sectional area is the total applied load in pounds divided by the gross cross-sectional area in square inches.

APPENDIX F

SPECIFICATIONS FOR STRUCTURAL WOOD JOIST, PLANKS, BEAMS, STRINGERS, AND POSTS

(American Society for Testing Materials)

(Serial Designation: D245-27)

A. STRUCTURAL GRADES OF LUMBER AND TIMBER AND THE METHOD OF THEIR DERIVATION

1. **Purpose.**—The purpose of structural grades is to offer means for selecting structural material for strength, and for uniformity in strength, in order that appropriate working stresses may be assigned for its use.

2. **Factors of Strength.**—The most important factors which influence the strength of structural material are the size, number and location of defects, and the extent of exposure to moisture during use. These factors must all be considered in design or grading if the maximum utilization is to be obtained from the material used.

3. **Structural Grades and Strength.**—Structural grades control defects by limiting their size and location in accordance with their effect upon strength. Working stresses for each species are recommended by the Forest Products Laboratory, U. S. Forest Service, and take into consideration the allowable defects, the moisture content as determined by conditions of use, and, in the case of southern pine and Douglas fir, rate of growth and percentage of summerwood.

4. **Moisture.**—Moisture affects the strength of structural timbers both directly and indirectly. The direct effect of loss of moisture is the stiffening and strengthening of the wood fibers. This increase in strength, however, is accompanied by checking, splitting, warping, and twisting; as a consequence, some of the strength due to drying is lost. Timbers are also subject, during use, to varying conditions of moisture, from the dry location of a heated building, to the continuously wet condition of some pier and dock timbers. All of these condition are taken into account in recommending working stresses under different conditions of use.

5. **Size Effects.**—In dimension material, 4 in. and less in thickness, the development of defects during seasoning does not offset the increase in strength from drying so much as in larger sizes, and in these sizes used in dry locations, higher working stresses in extreme fiber in bending can be recommended than in pieces of larger size having proportionately equivalent defects.

6. **Defects.**—The principal defects which must be limited in structural grades are knots, shakes and checks, and angle of grain.

7. **Influence of Knots.**—The influence of a knot is determined by its location in a piece and the area of its projection on the cross-section of the piece, the method of measurement being such as to give the best approximation of this influence. Knots in posts and heavy beams, which are likely to show only on one face or to run diagonally through the piece, reduce the strength in practically direct proportion to their size as measured. In dimension sizes, such as joist, in which the knot is likely to run directly through the piece, the strength is measured by the square of the effective depth, assuming the knot in its worst position, near the edge of the piece, and the reduction in strength due to the knot is approximately twice the ratio of the size of the knot to the width of the face. In similar material used flat, as plank, the influence of a knot is directly proportional to the size, as on the top and bottom edges of beams.

8. **Location of Knots, Joist, and Plank.**—Knot limitations on edges of wide faces of dimension sizes, for use as joist, are more severe than would be required for use flat, as plank, the sizes applying along the center lines of the wide faces as joist being those which could theoretically apply at any point across the width if used only as plank. It has been found, however, that under practically all conditions of use, knots along the edges of planks are more objectionable than knots along the center lines, and this is recognized in some commercial yard grades of plank in a stricter limitation of knots along the edges of the wide faces than along the center lines. The same knot limitations are applied, therefore, to material to be used either as joist or plank, and the same working stresses are assigned for use either on edge or flat.

9. **Increase in Size of Knots.**—In both joist and beams, knots reduce strength most along the top and bottom edges through the center portion. The sizes of knots permitted in various portions of a joist or beam are limited in accordance with the stresses, and they are allowed to increase toward the ends and toward the center lines of the vertical faces, no knot, however, being permitted of more than double the size allowed at the point of maximum stress.

10. **Small and Large Knots.**—There is greater proportional distortion of grain around a large knot than around a smaller one, and shrinkage in seasoning causes greater internal stresses, so knot sizes are increased proportionately to width of faces only up to 6-in. top and bottom faces of beams, 12-in. vertical faces of beams,

and 12-in. faces of dimension material and posts. Beyond these widths of face, increase is proportional to the square root of the ratio of the wider faces to these widths. The distribution and aggregate diameter of knots is limited as well as the maximum size of the single knot.

11. **Aggregate Diameter of Knots.**—The aggregate diameter of all knots in the center half of the length on any face of a beam or stringer shall be limited, in direct proportion to an aggregate diameter of twice the width of the face in a grade having 50 % of the strength of clear wood. In joist and plank, in dry locations, the aggregate diameter of knots in the center half of the length of any face may be greater by one-half the width of the face than the aggregate diameter permitted in beams and stringers. In posts and columns, the aggregate diameter of all knots in any 6 in. of length, in any grade, shall not exceed twice the size of the maximum knot allowable.

12. **Knots in Joist and Plank.**—In joist and plank, the mean or average diameter of a knot is taken as its size. In such thin and relatively wide material, whether used on edge or flat, this is a safe measure of the influence of knots on strength and has the commercial advantage of being directly applicable to yard grades of lumber. This method of measurement will exclude damaging spike knots and can be applied to them as well as to round or oval knots.

13. **Knots in Beams.**—On the top or bottom of a beam, the influence of knots is measured largely by the surface fibers cut. The projection of the knot on a line at a right angle to the edge is, therefore, used. On the vertical face of a beam, the depth to which a knot penetrates is of great importance, while the influence of the number of surface fibers cut, and the amount of grain distortion, is considerably less important than on the horizontal faces. The smallest diameter of the knot is, therefore, used.

14. **Spike Knots.**—One of the best examples illustrating the reason for the smallest diameter's being taken on the vertical face is the splitting of a boxed-heart timber into two pieces. The long spike knots which might be opened up in this way would be no more injurious to the strength of the two pieces than they would as a single knot in a boxed-heart piece, and the two pieces so cut would be less subject to seasoning checks than a boxed-heart piece.

15. **Knots in Columns.**—In columns there are two factors—area of cross-section occupied by a knot, which would probably be measured best by the small diameter of the knot; and the influence of bending stresses when the column begins to fail, probably measured best by the projection of the knot. In short columns, the area of the cross-section is of primary importance; as the column gets longer, the factor of bending strength increases in importance until the condition of the Euler formula is reached, when stiffness, on which knots have practically no influence, becomes the ruling factor. The average diameter, therefore, is used as that which applies best to the average condition.

16. **Knots and Holes.**—In grades for structural uses, no distinction is made between intergrown knots and encased knots or knot holes, observation at the Forest Products Laboratory in recent tests having shown that intergrown knots reduce strength fully as much as encased knots or knot holes.

17. **Shakes and Checks.**—Shakes reduce the area of a beam acting in resistance to shear, and the limitations placed on shakes are based on this reduction. Checks are limited on the same basis as shakes, and no combination of shakes and checks is permitted which would reduce strength to a greater extent than would the allowable size of either separately.

18. Shakes and checks in dense select and select joist and plank shall not exceed when green one-fourth the width of end nor when seasoned one-third the width of end.

Shakes and checks in common joist and plank shall not exceed when green four-tenths the width of end nor when seasoned four-ninths the width of end.

Shakes and checks in dense select and select beams and stringers shall not exceed when green one-fourth the width of end nor when seasoned one-third the width of end.

Shakes and checks in common beams and stringers shall not exceed when green four-tenths the width of end nor when seasoned four-ninths the width of end.

Shakes and checks in dense select and select posts and timbers shall not exceed when green four-tenths the width of end nor when seasoned one-half the width of end.

Shakes and checks in common posts and timbers shall not exceed when green one-half the width of end nor when seasoned six-tenths the width of end.

19. **Slope of Grain.**—Slope of grain, resulting either from diagonal sawing or from spiral or twisted grain in the log, is limited in accordance with the recommendation of the Forest Products Laboratory, based on the results of detailed study of the effect of cross- and spiral grain upon strength and the weakening of material by checks which invariably develop and, without exception, follow the grain. There is not much reduction in strength from cross-grain until an angle of grain of 1 in 40 is reached. From that slope in a beam an angle of grain of 1 in 20 reduces the strength about one-eighth; 1 in 15, about one-quarter; 1 in 11, about three-eighths; and 1 in 8, about one-half. In a post or column an angle of grain of 1 in 15 reduces the strength about one-eighth; 1 in 11, about one-quarter; 1 in 8, about three-eighths; and 1 in 6, about one-half.

20. **Wane and Knots.**—Wane is limited by such consideration as bearing area, nailing edge, appearance, etc., rather than by effect on strength. The percentage reduction in strength resulting from wane toward the center of a beam is about double the percentage reduction in cross-sectional area. No combination of wane and knots is permitted which would reduce the strength more than the maximum allowable knot. The occurrence of maximum wane and maximum knot in the same cross-section at the center of a beam would be so rare, however, and the effect of allowable maximum wane is so small a percentage of the effect of maximum allowable knot, that the additional reduction in strength beyond the effect of the knot would be slight, and it is usually unnecessary to give attention to combination of wane and knot.

21 **Pitch Pockets.**—Pitch pockets are ordinarily not defects in a structural grade. A large number, however, indicates a general lack of bond, and such a piece should be carefully inspected for shakes.

22. Heartwood and Sapwood.—Heartwood and sapwood have been found by the Forest Products Laboratory to be of equal strength, and no requirement of heartwood need be made when strength alone is the governing factor. Heart requirement, when durability of untreated material under exposure is a factor, as in bridges, trestles, docks and piers, or in damp buildings or buildings in which conditions of high humidity prevail, may be specified in any grade, according to exposure and use. When preservative treatment is to be applied, there should be no restriction as to sapwood, as sapwood is easier to treat than heartwood, and a large amount is to be preferred.

23. Density and Strength.—The density of the wood substance of all species is practically the same. The dry weight is, therefore, a measure of the amount of wood substance present; and on the amount of wood substance present depends the strength of the clear wood. No pieces of exceptionally light weight are permitted in the select grades, but light-weight pieces otherwise of select grade may be accepted in the common grades.

24. Density and Summerwood.—In southern pine and Douglas fir, the proportion of summerwood—the dark portion of the annual ring—furnishes a practical means of estimating density. Selection of these species for density, to the extent that dense material is commercially available, assures material of the highest character from the standpoint of strength, and uniformity in strength, in the clear wood.

25. Rate of Growth and Strength.—Selection of these species for rate of growth is not so great an assurance of increased strength as selection for percentage of summerwood, but for many purposes selection for rate of growth will assure material of suitable type. Close grain, that is, not less than 6 nor more than 20 annual rings per inch, is required in the select structural grades of these species.

26. Contrast between Summerwood and Springwood.—In acceptance for density the contrast in color between summerwood and springwood should be distinct. Absence of contrast occasionally occurs in bands of growth rings which appear, on the whole, darker in color than the adjacent material. The summerwood merges into the springwood abnormally with a gradual change of color, leaving practically no material which has the normal appearance of springwood. Such material has been called by a number of names, including proudwood, redwood, and compressionwood. It has a decided end shrinkage, is weak in tension, and even a small part of a cross-section of this character is undesirable in high-class structural timbers.

27. Minimum Requirements and Maximum Defects.—Structural grades specify minimum requirements and maximum defects, all of which may be present at one time. When a particular piece which is being inspected, therefore, is slightly below the provisions of the grade in some respects but is of average density or above, the relative effect on the properties affected should be given consideration

28. Re-inspection.—In inspection for density, reasonable variation of opinion among inspectors should be recognized. A fair provision for re-inspection of a particular lot of timbers for density would be that for every three timbers accepted as having one-third or more summerwood, one of the remaining timbers be accepted if having 30 and 33⅓ % summerwood.

29. Yard Grades and Cutting Grades.—A large percentage of material in standard yard grades of "dimension" and "timbers" will meet the additional requirements of structural grades for joist and plank and posts and timber, and material to meet these requirements can easily be selected from local stocks: select from select common and merchantable grades, and common from No. 1 common grade. Beams and stringers vary materially in size and are not stocked extensively. These are essentially special-order grades.

30. Joist and Plank, Beams and Stringers.—As previously noted, the provisions of the joist-and-plank grades are such that material graded by them may be used on edge, as joist or rafters, or flat, as scaffold plank or factory flooring. Joist-and-plank grades apply to material not thicker than 4 in. Material thicker than 4 in. for use in bending should be graded by beam-and-stringer grades. In such material with loads applied to the wide face, the knot requirements for this face are those for the narrow face as given in the rules.

31. Timbers Used as Beams and Stringers.—Material to be used for such purposes as caps, bridge ties, etc., where strength in bending is a factor, should be specified in beam-and-stringer grades although of shape more commonly considered as of timber grades, as the method of measuring knots in post-and-timber grades makes it impracticable to assign bending stresses to them Caps and bridge ties are often square or have horizontal faces wider than the vertical faces, in contrast to beams and stringers in which the narrow faces are horizontal faces and the wide faces are vertical, and this should be noted in applying the knot provisions of the beam-and-stringer grade to such material.

Introduction to Structural Rules

32. The following rules for structural grades conform to the Basic Provisions for the Selection and Inspection of Softwood Dimension and Timbers where Working Stresses Are Required accepted at the General Lumber Conference, Washington, D. C., May 1, 1925, as the basis for the preparation of grading rules for structural material.

33. They are complete rules, covering all conditions necessary for consideration in structural grading, and are divided into sections from which combinations are made covering specific purposes and conditions.

34. These specifications may be used for mill orders and for selection from or appraisal of stock on hand in manufacturers', middlemen's, or users' stock.

35. The rules cover the following grades and use classifications:

Grades	
Dense select	Douglas fir and southern pine
Select	Douglas fir and southern pine
Select	Other softwood species
Common	All softwood species

Uses	
Joist and plank	Joist. rafters, bracing, scaffold plank, factory flooring, etc.
Beams and stringers	Beams, girders, stringers, bridge ties, caps, etc.
Posts and timbers	Posts, sills, caps, timbers, etc.
Optional Provisions	
Wane	Where permissible
Square edges	Where required or desired
Heartwood requirement	For durability of untreated timbers
Sapwood permissibility	For material to be treated

SIZES OF JOIST AND PLANK

Joist, rafters, scaffold plank, factory flooring, etc.	
Nominal thickness	2 to 4 in.
Nominal widths	4 in and wider
Standard thickness	S1S or S2S: ⅜ in. off
Standard widths	2 to 7 in., S1E or S2E: ⅜ in. off 8 in. and wider, S1E or S2E: ½ in. off

SIZES OF BEAMS AND STRINGERS

Beams, Girders, Stringers, etc.	
Nominal thickness	5 in. and thicker
Nominal widths	8 in. and wider

SIZES OF POSTS AND TIMBERS

Posts, Caps, Sills, Timbers, etc.	
Nominal sizes	6 × 6 in. and larger

B SPECIFICATION REQUIREMENTS FOR STRUCTURAL WOOD JOIST, PLANK, BEAMS, STRINGERS, AND POSTS

TIMBER-SIZE REQUIREMENTS

1. (*a*) **Joist and Plank, Surfaced.**—Structural joist and plank shall be when surfaced S1S or S2S not thinner than the nominal dimension less ⅜ in. and when surfaced S1E or S2E not narrower than the nominal width less ⅜ in. for sizes 2 to 7 in. inclusive and less ½ in. for sizes 8 in. and wider.

1. (*b*) **Beams and Stringers, Posts and Timbers, Surfaced.**—Structural beams and stringers and posts and timbers shall be, when surfaced S1S, S1E, S2S, S1S, not smaller than the nominal size less ⅜ in. for sizes 7 in. and less and less ½ in. for sizes 8 in. and over.

1. (*c*) **Joist and Plank, Rough.**—Rough structural joist and plank shall not be thinner than the nominal dimension less ¼ in. and not narrower than the nominal width less ¼ in. for sizes 2 to 7 in. inclusive and less ⅜ in. for sizes 8 in. and wider.

1. (*d*) **Beams and Stringers, Posts and Timbers, Rough.**—Rough structural beams and stringers and posts and timbers shall not be smaller than the nominal size less ¼ in. for sizes 7 in. and less, and less ⅜ in. for sizes 8 in. and over.

GRADE REQUIREMENTS

2. **Sound Wood.**—This material shall contain only sound wood.

GENERAL

3. (*a*) **Weight.**—No pieces of exceptionally light weight shall be permitted, except that light-weight pieces otherwise of select grade may be accepted in common grade.

(*b*) **Shake, Checks and Splits.**—Shake shall be measured on the ends of a piece, and its size shall be taken as the shortest distance between lines enclosing the shake and parallel to the wide faces of the piece. Checks and splits shall be limited as provided for shakes. No checks or combinations of checks with shakes which would reduce the strength to a greater extent than the allowable shake shall be permitted.

(*c*) **Wane and Knots.**—Where wane is permitted, there shall be no combination of wane and knots which would reduce the strength more than the maximum allowable knot.

(*d*) **Cluster Knots.**—Cluster knots and knots in groups are not permitted.

(*e*) **Holes.**—Knot holes and holes from other causes than knots shall be permitted as provided for knots.

(*f*) **Knot Measurement.**—The size of a knot shall be measured on the section of the knot appearing on the surface under consideration.

(*g*) **Mean Diameter.**—When the mean or average diameter of a knot is specified, the size shall be taken as the average of the maximum and minimum diameters.

(*h*) **Spike Knots.**—Knot sizes specified shall be applied to spike knots as well as to round knots.

(*i*) **Spike Knot Mean Diameter.**—The mean or average diameter of a spike knot shall be taken as the average of its length and its maximum width.

KNOTS

Joist and Plank

4. (*a*) **Wide Faces.**—On the wide faces of joist and plank, the measurement of a knot shall be made on the mean or average diameter.

(*b*) **Narrow Faces.**—On the narrow faces of joist and plank, the size of a knot shall be taken as its width between lines parallel to the edges of the piece.

(*c*) **Increase to Ends.**—The size of knots on the narrow faces and edges of wide faces of joist and plank may increase proportionately from the size allowed in the middle third to twice that size at the ends of the pieces.

(*d*) **Increase to Center Line.**—The size of knots on the wide faces of joist and plank may increase proportionately from the size allowed at the edge to that allowed at the center line.

Beams and Stringers

5. (*a*) **Narrow Faces.**—On the narrow or horizontal faces of beams and stringers the size of a knot shall be taken as its width between lines parallel to the edges of the timber.

(*b*) **Wide Faces.**—On the wide or vertical faces of beams and stringers the smallest diameter of a knot shall be taken as its size.

(*c*) **Edges.**—Knots on the edges of wide or vertical faces of beams and stringers are limited to the same size as on the adjacent narrow or horizontal faces, except that the size is measured on the least diameter of the knot instead of on its width between lines parallel to the edges of the timber.

(*d*) **Increase to Ends.**—The size of knots on the narrow or horizontal faces and edges of wide or vertical faces of beams and stringers may increase proportionately from the size allowed in the middle third to twice that size at the ends of the piece.

(*e*) **Increase to Center Line.**—The size of knots on the wide or vertical faces of beams and stringers may increase proportionately from the size allowed at the edge to that allowed at the center line.

Posts and Timbers

6. **Mean Diameter.**—In posts and timbers, the measurement of a knot shall be made on the mean or average diameter.

7. **Maximum Size of Knots in Dense Select and Select Joist and Plank.**

(*a*) Knots on Wide Faces

Width of face, inches	Size of knot, inches	
	On or near edge, middle third of length	Center line of face
4	¾	1½
6	1	2
8	1⅜	2⅝
10	1¾	3¼
12	2⅛	4
14	2⅜	4¼
16	2½	4⅝

(*b*) Knots on Narrow Faces of Boxed-heart Pieces

Thickness of piece, inches	Size of knot, inches Middle third of length
2	⅝
3	1
4	1¼

(*c*) The sum of the diameters of all knots within the center half of the length of a joist or plank on any face shall not exceed one and one-half times the width of face on which they occur

8. **Maximum Size of Knots in Common Joist and Plank.**

(*a*) Knots on Wide Faces

Width of face, inches	Size of knot, inches	
	On or near edge, middle third of length	Center line of face
4	1	1¾
6	1½	2½
8	2	3⅜
10	2½	4¼
12	3	5⅛
14	3¼	5¾
16	3⅜	6

(b) KNOTS ON NARROW FACES OF BOXED-HEART PIECES

Thickness of piece, inches	Size of knot, inches Middle third of length
3	1¼
4	1¾

(c) The sum of the diameters of all knots within the center half of the length of a joist or plank on any face shall not exceed twice the width of face on which they occur.

9. **Maximum Size of Knots in Dense Select and Select Beams and Stringers.** (a)

Width of face, inches	Size of knot, inches	
	Narrow or horizontal face, middle third of length	Center line of wide or vertical face
5	1¼	1¼
6	1½	1½
8	1¾	2
10	2	2½
12	2⅛	3
14	2¼	3¼
16	2⅜	3⅜
18	..	3⅝
20	...	3⅞
22	..	4
24	...	4¼

(b) The sum of the diameters of all knots within the center half of the length of a beam or stringer on any face shall not exceed the width of face on which they occur.

10. (a) **Maximum Size of Knots in Common Beams and Stringers.**

Width of face, inches	Size of knot, inches	
	Narrow or horizontal face, middle third of length	Center line of wide face or vertical face
5	2	2
6	2⅜	2⅜
8	2¾	3⅛
10	3⅛	4
12	3¾	4¾
14	3⅝	5⅛
16	3⅞	5½
18	. .	5⅝
20	...	6⅛
22	...	6½
24	..	6¾

(b) The sum of the diameters of all knots within the center half of the length of a beam or stringer on any face shall not exceed one and one-half times the width of face on which they occur.

11. (a) **Maximum Size of Knots in Dense Select and Select Posts and Timbers.**

Width of face, inches	Size of knot, inches
6	1½
8	2
10	2½
12	3
14	3¼
16	3⅜
18	3⅝
20	3⅞
22	4
24	4¼

(b) The sum of the diameters of all knots in any 6 in. of length of a post or timber shall not exceed twice the size of the maximum knot allowable.

12. (*a*) Maximum Size of Knots in Common Posts and Timbers.

Width of face, inches	Size of knot, inches
6	2⅜
8	3⅛
10	4
12	4¾
14	5⅛
16	5½
18	5⅞
20	6⅛
22	6½
24	6¾

(*b*) The sum of the diameters of all knots in any 6 in. of length of a post or timber shall not exceed twice the size of the maximum knot allowable.

SHAKE AND CHECKS

13. Maximum Shake and Checks in Dense Select and Select Joist and Plank.

Width of end, inches	Size of shake or check, inches	
	Green	Seasoned
2	½	⅝
3	¾	1
4	1	1¼

14. Maximum Shake and Checks in Common Joist and Plank.

Width of end, inches	Size of shake or check, inches	
	Green	Seasoned
2	¾	⅞
3	1⅛	1¼
4	1½	1¾

15. Maximum Shake and Checks in Dense Select and Select Beams and Stringers.

Width of end, inches	Size of shake or check, inches	
	Green	Seasoned
6	1½	2
8	2	2⅝
10	2½	3¼
12	3	4
14	3½	4⅝
16	4	5¼
18	4½	6
20	5	6⅝
22	5½	7¼
24	6	8

16. Maximum Shake and Checks in Common Beams and Stringers.

Width of end, inches	Size of shake or check, inches	
	Green	Seasoned
5	2	$2\frac{1}{8}$
6	$2\frac{3}{8}$	$2\frac{5}{8}$
8	$3\frac{1}{8}$	$3\frac{1}{2}$
10	4	$4\frac{5}{8}$
12	$4\frac{3}{4}$	$5\frac{1}{4}$
14	$5\frac{1}{2}$	$6\frac{1}{8}$
16	$6\frac{3}{8}$	7
18	$7\frac{1}{8}$	8
20	8	$8\frac{7}{8}$
22	$8\frac{3}{4}$	$9\frac{3}{4}$
24	$9\frac{1}{2}$	$10\frac{5}{8}$

17. Maximum Shake and Checks in Dense Select and Select Posts and Timbers.

Width of end, inches	Size of shake or check, inches	
	Green	Seasoned
5	2	$2\frac{1}{2}$
6	$2\frac{3}{4}$	3
8	$3\frac{1}{8}$	4
10	4	5
12	$4\frac{3}{4}$	6
14	$5\frac{1}{2}$	7
16	$6\frac{3}{8}$	8
18	$7\frac{1}{8}$	9
20	8	10
22	$8\frac{3}{4}$	11
24	$9\frac{1}{2}$	12

18. Maximum Shake and Checks in Common Posts and Timbers.

Width of end, inches	Size of shake or check, inches	
	Green	Seasoned
6	3	$3\frac{1}{2}$
8	4	$4\frac{3}{4}$
10	5	6
12	6	$7\frac{1}{8}$
14	7	$8\frac{3}{8}$
16	8	$9\frac{1}{2}$
18	9	$10\frac{3}{4}$
20	10	12
22	11	$13\frac{1}{8}$
24	12	$14\frac{5}{8}$

Slope of Grain

19. (a) *Dense Select and Select Joist and Plank.*—The slope of grain in the center half of length shall not exceed 1 in 12.

19. (b) *Common Joist and Plank.*—The slope of grain in the center half of length shall not exceed 1 in 10.

19. (c) *Dense Select and Select Beams and Stringers.*—The slope of grain in the center half of length shall not exceed 1 in 15.

19. (d) *Common Beams and Stringers.*—The slope of grain in the center half of length shall not exceed 1 in 10.

19. (e) *Dense Select and Select Posts and Timbers.*—The slope of grain shall not exceed 1 in 10.

19. (f) *Common Posts and Timbers.*—The slope of grain shall not exceed 1 in 8.

WANE OR SQUARE EDGES

20. **Wane One-eighth.**—(*a*) *Wane, Dense Select and Select Grade.*—Wane is permitted, not exceeding one-eighth the width of any face.

20. **Wane One-fourth.**—(*b*) *Wane, Common Grade.*—Wane is permitted, not exceeding one-fourth the width of any face.

20. **Square.**—(*c*) *Square Edges.*—All edges must be square.

HEARTWOOD AND SAPWOOD

Durability Untreated.—Heartwood requirements shall be specified as required from the following:

Heartwood Provisions:

21. (*a*) **Joist and Plank.**—Joist and plank shall have not less than 85 % of heart on the two faces, as measured across the faces anywhere in the length of the piece.

21. (*b*) **Beams and Stringers.**—Beams and stringers shall have not less than 85 % heart on each of the four faces, measured across the faces anywhere in the length of the piece.

21. (*c*) **Timbers, 85 %.**—Timbers designated 85 % shall have not less than 85 % heart on each of the four faces measured across the face anywhere in the length of the piece.

21. (*d*) **Timbers, One Face All Heart, Others 85 %.**—Timbers designated one face all heart, others 85 % shall have all heart on one narrow face, the other narrow face and the two sides shall have not less than 85 % of heart, measured across the face or sides anywhere in the length of the piece.

21. (*e*) **Timbers, One Face All Heart, Others 75 %.**—Timbers designated one face all heart, others 75 % shall have all heart on one narrow face, the other narrow face and the two sides shall have not less than 75 % of heart measured across the face or sides anywhere in the length of the piece

For Treatment

Provision for sapwood for timber to be treated is covered by the following:

Sapwood Provisions:

22. There is no restriction as to sapwood for this material.

Rate of Growth and Density

Select.—Southern pine or Douglas fir of select grade is to be selected for close grain.

Dense Select.—Southern pine or Douglas fir of dense select grade is to be selected for density.

Close Grain

23. Douglas fir or southern pine shall be of close grain, averaging on either one end or the other not less than 6 nor more than 20 annual rings per inch measured over a 3-in. portion of a radial line located as described below and representative of the average growth on the cross-section. Pieces averaging from five to six annual rings per inch shall be accepted as the equivalent of close grain if having one-third or more summerwood.

Density

24. Douglas fir or southern pine shall be dense, averaging on either one end or the other not less than six annual rings per inch and, in addition, one-third or more summerwood measured over a 3-in. portion of a radial line located as described below and representative of the average growth on the cross-section. The contrast in color between summerwood and springwood shall be distinct. Coarse-grained material excluded by this rule shall be accepted as dense if averaging one-half or more summerwood.

Close Grain or Density

25. **Radial Line Not Representative.**—When the radial line specified is not representative, it shall be shifted sufficiently to present a fair average, but the distance from the pith to the beginning of the 3-in. portion of the line in boxed-heart pieces shall not be changed.

26. **Close Grain on Two Radial Lines**—In case of disagreement in the measurement of close grain, two radial lines shall be chosen, and the number of rings shall be the average determined on these lines.

27. **Density on Two Radial Lines.**—In case of disagreement in the measuremen of density, two radial lines shall be chosen, and the number of rings and summerwood shall be the average determined on these lines.

Location of Radial Line

In Douglas Fir:

28. (*a*) **Side-cut Pieces.**—In side-cut pieces of Douglas fir, the radial line shall be at a right angle to the annual rings and the center of the 3-in. portion of the line shall be at the center of the end of the piece.

(*b*) **Boxed-heart Pieces.**—In box-heart pieces, the line shall run from the pith to the corner farthest from the pith. When the least dimension is 6 in. or less, the 3-in. portion of the line shall begin at a distance of 1 in. from the pith. When the least dimension is more than 6 in., the 3-in. portion of the line shall begin at a distance from the pith equal to 2 in. less than one-half the least dimension of the piece.

(*c*) If a 3-in. portion of the radial line cannot be obtained, the measurement shall be made over as much of the 3-in. portion as is available.

In Southern Pine:

29. **Boxed-heart Pieces.**—(*a*) In boxed-heart pieces of southern pine, the measurement shall be made over the third, fourth, and fifth inches from the pith along the radial line.

(b) Pith Not Present.—In cases where timbers do not contain the pith, and it is impossible to locate it with any degree of accuracy, the inspection shall be made over 3 in. on an approximate radial line beginning at the edge nearest the pith in timbers over 3 in. in thickness and on the second inch nearest the pith in timbers 3 in. or less in thickness.

(c) Pith Present, but Less Than 5-in. Radial Line.—In material containing the pitch but not a 5-in. radial line, which is less than 2 × 8 in. in section or less than 8 in. in width, that does not show over 16 sq. in. on the cross-section, the inspection shall apply to the second inch from the pith. In larger material that does not show a 5-in. radial line, the inspection shall apply to the third inch farthest from the pith.

C. STRUCTURAL GRADES AND REFERENCE CODE

The individual specifications are divided into sections with general numbers for reference.

Where alternate requirements are listed, each has a capital letter added to the general number. For any material, appropriate choice must be made of such paragraphs.

Where several paragraphs occur under the general number and each is designated by a small letter, all such paragraphs must be used in making a complete specification.

In cases where only a small number of sizes are ordered it is permissible to shorten the tables of maximum defects by only copying sizes of defects corresponding with the sizes being ordered.

Three complete specifications are shown to illustrate the application of the code.

These are followed by a complete list of numbered specifications, brief description of material, and appropriate code numbers of sections required to write a complete specification for this material.

TYPICAL SPECIFICATIONS FOR DENSE SELECT BEAMS AND STRINGERS (SOUTHERN PINE) WITH SQUARE EDGES AND HEARTWOOD REQUIREMENT FOR USE UNTREATED, ROUGH

(Specification Reference No. 1 in Subdivision *D* on Coded Specifications)

TIMBER-SIZE REQUIREMENTS

1*D*. Rough structural beams and stringers shall not be smaller than the nominal size less ¼ in. for sizes 7 in. and less, and less ⅜ in. for sizes 8 in. and over.

GRADE REQUIREMENTS

2. The material shall contain only sound wood.

General

3. (*a*) No pieces of exceptionally light weight shall be permitted except that light-weight pieces otherwise of select grade may be accepted in common grade.

(*b*) Shake shall be measured on the ends of a piece, and its size shall be taken as the shortest distance between lines enclosing the shake and parallel to the wide faces of the pieces. Checks and splits shall be limited as provided for shakes. No checks or combinations of checks with shakes which would reduce the strength to a greater extent than the allowable shake shall be permitted.

(*c*) Where wane is permitted there shall be no combination of wane and knots which would reduce the strength more than the maximum allowable knot

(*d*) Cluster knots and knots in groups are not permitted.

(*e*) Knot holes and holes from other causes than knots shall be permitted as provided for knots.

(*f*) The size of a knot shall be measured on the section of the knot appearing on the surface under consideration.

(*g*) When the mean or average diameter of a knot is specified, the size shall be taken as the average of the maximum and minimum diameters.

(*h*) Knot sizes specified shall be applied to spike knots as well as to round knots.

(*i*) The mean or average diameter of a spike knot shall be taken as the average of its length and its maximum width.

Knots

Beams and Stringers

5. (*a*) On the narrow or horizontal faces of beams and stringers the size of a knot shall be taken as its width between lines parallel to the edges of the timber.

(*b*) On the wide or vertical faces of beams and stringers the smallest diameter of a knot shall be taken as its size.

(*c*) Knots on the edges of wide or vertical faces of beams and stringers are limited to the same size as on the adjacent narrow or horizontal faces, except that the size is measured on the least diameter of the knot instead of on its width between lines parallel to the edges of the timber.

(*d*) The size of knots on the narrow or horizontal faces and edges of wide or vertical faces of beams and stringers may increase proportionately from the size allowed in the middle third to twice that size at the ends of the piece.

(*e*) The size of knots on the wide or vertical faces of beams and stringers may increase proportionately from the size allowed at the edge to that allowed at the center line.

(*a*) ***Maximum Size of Knots in Dense Select and Select Beams and Stringers.***

Width of face, inches	Size of knot, inches	
	Narrow or horizontal face, middle third of length	Center line of wide or vertical face
5	1¼	1¼
6	1½	1½
8	1¾	2
10	2	2½
12	2⅛	3
14	2¼	3¼
16	2⅜	3⅜
18	...	3⅝
20	..	3⅞
22	...	4
24	...	4¼

(*b*) The sum of the diameters of all knots within the center half of the length of a beam or stringer on any face shall not exceed the width of the face on which they occur.

SHAKE AND CHECKS

15. *Maximum Shake and Checks in Dense Select and Select Beams and Stringers.*

Width of end, inches	Size of shake or check, inches	
	Green	Seasoned
6	1½	2
8	2	2⅝
10	2½	3¼
12	3	4
14	3½	4⅝
16	4	5¼
18	4½	6
20	5	6⅝
22	5½	7¼
24	6	8

19*C*. The slope of grain in center half of length shall not exceed 1 in 15.

20*C*. All edges must be square.

21*B*. Beams and stringers shall have not less than 85 % heart on each of the four faces measured across the faces anywhere in the length of the piece.

24. Southern pine shall be dense, averaging on either one end or the other not less than six annual rings per inch and, in addition, one-third or more summerwood measured over a 3-in. portion of a radial line located as described below and representative of the average growth on the cross-section. The contrast in color between summerwood and springwood shall be distinct. Coarse-grained material excluded by this rule shall be accepted as dense if averaging one-half or more summerwood.

25. When the radial line specified is not representative, it shall be shifted sufficiently to present a fair average, but the distance from the pith to the beginning of the 3-in. portion of the line in boxed-heart pieces shall not be changed.

27. In case of disagreement, two radial lines shall be chosen, and the number of rings and summerwood shall be the average determined on these lines.

29(*a*) In boxed-heart pieces of southern pine, the measurement shall be made over the third, fourth, and fifth inches from the pith along the radial line.

(*b*) In cases where the timbers do not contain the pith, and it is impossible to locate it with any degree of accuracy, the inspection shall be made over 3 in. on an approximate radial line beginning at the edge nearest the pith in timbers over 3 in. in thickness and on the second inch nearest to the pith in timbers 3 in. or less in thickness.

(*c*) In material containing the pith but not a 5-in. radial line, which is less than 2 × 8 in. in section or less than 8 in. in width, that does not show over 16 sq. in. on the cross-section, the inspection shall apply to the second inch from the pith. In larger material that does not show a 5-in. radial line, the inspection shall apply to the 3 in. farthest from the pith.

TYPICAL SPECIFICATION FOR SELECT POSTS AND TIMBERS (DOUGLAS FIR) WITH WANE PERMITTED AND SAPWOOD WANTED FOR TREATMENT, SURFACED FOUR SIDES

(Specification Reference No. 50 in Subdivision *D* on Coded Specifications)

TIMBER-SIZE REQUIREMENTS

1*B*. Structural posts and timbers shall be, when surfaced S1S, S1E, S2S, S4S, not smaller than the nominal size less 3/8 in. for sizes 7 in. and less and less 1/2 in. for sizes 8 in. and over.

GRADE REQUIREMENTS

2. The material shall contain only sound wood.

General

3. (*a*) No pieces of exceptionally light weight shall be permitted, except that light-weight pieces otherwise of select grade may be accepted in common grade.

(*b*) Shake shall be measured on the ends of a piece, and its size shall be taken as the shortest distance between lines enclosing the shake and parallel to the wide faces of the piece. Checks and splits shall be limited as provided for shakes. No checks or combination of checks with shakes which would reduce the strength to a greater extent than the allowable shake shall be permitted.

(*c*) Where wane is permitted there shall be no combination of wane and knots which would reduce the strength more than the maximum allowable knot.

(*d*) Cluster knots and knots in groups are not permitted.

(*e*) Knot holes and holes from other causes than knots shall be permitted as provided for knots.

(*f*) The size of a knot shall be measured on the section of the knot appearing on the surface under consideration.

(*g*) When the mean or average diameter of a knot is specified, the size shall be taken as the average of the maximum and minimum diameters.

(*h*) Knot sizes specified shall be applied to spike knots as well as to round knots.

(*i*) The mean or average diameter of a spike knot shall be taken as the average of its length and its maximum width.

Knots

6. In posts and timbers, the measurement of a knot shall be made on the mean or average diameter.

11. (*a*) *Maximum Size of Knots in Dense Select and Select Posts and Timbers.*

Width of face, inches	Size of knot, inches
6	1½
8	2
10	2½
12	3
14	3¼
16	3⅜
18	3⅝
20	3⅞
22	4
24	4¼

(*b*) The sum of the diameters of all knots in any 6 in. of length of a post or timber shall not exceed twice the size of the maximum knot allowable.

Shake and Checks

17. *Maximum Shake and Checks Dense Select and Select Posts and Timbers.*

Width of end, inches	Size of shake or check, inches	
	Green	Seasoned
5	2	2½
6	2⅜	3
8	3⅛	4
10	4	5
12	4¾	6
14	5½	7
16	6⅜	8
18	7⅛	9
20	8	10
22	8¾	11
24	9½	12

19*E*. The slope of grain shall not exceed 1 in 10.

20*A*. Wane is permitted, not exceeding one-eighth the width of any face.

22. There is no restriction as to sapwood for this material.

23. Douglas fir shall be of close grain, averaging on either one end or the other not less than 6 nor more than 20 annual rings per inch measured over a 3-in. portion of a radial line located as described below and representative of the average growth on the cross-section. Pieces averaging from five to six annual rings per inch shall be accepted as the equivalent of close grain if having one-third or more summerwood.

25. When the radial line specified is not representative, it shall be shifted sufficiently to present a fair average, but the distance from the pith to the beginning of the 3-in. portion of the line in boxed-heart pieces shall not be changed.

26. In case of disagreement, two radial lines shall be chosen, and the number of rings shall be the average determined on these lines.

28(*a*) In side-cut pieces of Douglas fir, the radial line shall be at a right angle to the annual rings, and the center of the 3-in. portion of the line shall be at the center of the end of the piece.

(*b*) In boxed-heart pieces the line shall run from the pith to the corner farthest from the pith. When the least dimension is 6 in. or less, the 3-in. portion of the line shall begin at a distance of 1 in. from the pith. When the least dimension is more than 6 in., the 3-in. portion of the line shall begin at a distance from the pith equal to 2 in. less than one-half the least dimension of the piece.

(*c*) If a 3-in. portion of a radial line cannot be obtained, the measurement shall be made over as much of the 3-in. portion as is available.

TYPICAL SPECIFICATION FOR COMMON JOIST AND PLANK WITH WANE PERMISSIBILITY AND NO HEARTWOOD OR SAPWOOD REQUIREMENT, SURFACED S1S, S1E

(Specification Reference No. 38 in Subdivision *D* on Coded Specifications)

TIMBER-SIZE REQUIREMENTS

1*A*. Structural joist and plank shall be, when surfaced S1S or S2S, not thinner than the nominal dimension less ⅜ in. and when surfaced S1E or S2E not narrower than the nominal width less ⅜ in. for sizes 2 to 7 in. inclusive and less ½ in. for sizes 8 in. and wider.

GRADE REQUIREMENTS

2. The material shall contain only sound wood.

General

3. (*a*) No pieces of exceptionally light weight shall be permitted, except that light-weight pieces otherwise of select grade may be accepted in common grade.

(*b*) Shake shall be measured on the ends of a piece, and its size shall be taken as the shortest distance between lines enclosing the shake and parallel to the wide faces of the piece. Checks and splits shall be limited as provided for shakes. No checks or combination of checks with shakes which would reduce the strength to a greater extent than the allowable shake shall be permitted.

(*c*) Where wane is permitted there shall be no combination of wane and knots which would reduce the strength more than the maximum allowable knot.

(*d*) Cluster knots and knots in groups are not permitted.

(*e*) Knot holes and holes from other causes than knots shall be permitted as provided for knots.

(*f*) The size of a knot shall be measured on the section of a knot appearing on the surface under consideration

(*g*) When the mean or average diameter of a knot is specified, the size shall be taken as the average of the maximum and minimum diameters.

(*h*) Knot sizes specified shall be applied to spike knots as well as to round knots.

(*i*) The mean or average diameter of a spike knot shall be taken as the average of its length and its maximum width.

Knots

(4) (*a*) On the wide faces of joist and plank, the measurement of a knot shall be made on the mean or average diameter.

(*b*) On the narrow faces of joist and plank, the size of a knot shall be taken as its width between lines parallel to the edges of the piece.

(*c*) The size of knots on the narrow faces and edges of wide faces of joist and plank may increase proportionately from the size allowed in the middle third to twice that size at the ends of the pieces.

(*d*) The size of knots on the wide faces of joist and plank may increase proportionately from the size allowed at the edge to that allowed at the center line.

(8) (*a*) ***Maximum Size of Knots in Common Joist and Plank, Knots on Wide Faces.***

Width of face, inches	Size of knot, inches	
	On or near edge, middle third of length	Center line of face
4	1	1¾
6	1½	2½
8	2	3⅜
10	2½	4¼
12	3	5⅛
14	3¼	5⅝
16	3⅜	6

(*b*) ***Knots on Narrow Faces of Boxed Heart Pieces.***

Thickness of piece, inches	Size of knot, inches Middle third of length
	1¼
	1¾

(*c*) The sum of the diameters of all knots within the center half of the length of a joist or plank on any face shall exceed twice the width of face on which they occur.

SHAKE AND CHECKS

14. ***Maximum Shake and Checks in Common Joist and Plank.***

Width of end, inches	Size of shake or check, inches	
	Green	Seasoned
2	¾	⅞
3	1⅛	1¼
4	1½	1¾

19*B*. ***Common Joist and Plank.***—The slope of grain in the center half of length shall not exceed 1 in 10.
20*B*. ***Wane, Common Grade.***—Wane is permitted, not exceeding one-fourth the width of any face.

D. CODED SPECIFICATIONS FOR STRUCTURAL GRADES

INDEX TO CODED-SPECIFICATION REFERENCE NUMBERS

Grades	Additional requirements						
	For use untreated					For treating	
	For durability heartwood required			No heartwood or sapwood required		Sapwood not restricted	
	One face 100 %; other three faces 85 %	All faces 85 %	One face 100 %; other three faces 75 %				
	Square edge			Square edge	Wane permitted	Square edge	Wane permitted
Beams and stringers							
Dense select:							
Douglas fir or southern pine ...	..	1	..	2	3	4	5
Select:							
Douglas fir or southern pine	..	6	..	7	8	9	10
Select:							
Any other softwood..	..	11	..	12	13	14	15
Common:							
Any softwood..	..	16	..	17	18	19	20
Joist and plank							
Dense select:							
Douglas fir or southern pine	..	21	..	22	23	24	25
Select:							
Douglas fir or southern pine.......	..	26	..	27	28	29	30
Select:							
Any other softwood..	..	31	..	32	33	34	35
Common:							
Any softwood.	..	36	..	37	38	39	40
Posts and timbers							
Dense select:							
Douglas fir or southern pine.......	61	41	65	42	43	44	45
Select:							
Douglas fir or southern pine.	62	46	66	47	48	49	50
Select:							
Any other softwood..............	63	51	67	52	53	54	55
Common:							
Any softwood...........	64	56	68	57	58	59	60

Dense Select Beams and Stringers

No. 1. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE, DENSE SELECT, 85 % HEARTWOOD, SQUARE EDGES:
1B (surfaced) or 1D (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9$(a + b)$, 15, 19C, 20C, 21B, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 2. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE, DENSE SELECT, NO HEARTWOOD OR SAPWOOD REQUIREMENT, SQUARE EDGES:
1B (surfaced) or 1D (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19C, 20C, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 3. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE DENSE SELECT, NO HEARTWOOD OR SAPWOOD REQUIREMENT, WANE PERMITTED:
1B (surfaced) or 1D (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19C, 20A, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 4. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE, DENSE SELECT, SAPWOOD WANTED FOR TREATMENT, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*C*, 22, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 5. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE, DENSE SELECT, SAPWOOD WANTED FOR TREATMENT, WANE PERMITTED:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*A*, 22, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

Select Beams and Stringers

No 6. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE, SELECT, 85 % HEARTWOOD, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*C*, 21*B*, 23, 25, 26, 28 $(a + b + c)$, Douglas fir on 29 $(a + b + c)$ southern pine.

No. 7. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE, SELECT, NO. HEARTWOOD OR SAPWOOD REQUIREMENT, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*C*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 8. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE, SELECT, NO HEARTWOOD OR SAPWOOD REQUIREMENT, WANE PERMITTED:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*A*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 9. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE, SELECT, SAPWOOD WANTED FOR TREATMENT, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough) 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$ 15, 19*C*, 20*C*, 22, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 10. BEAMS AND STRINGERS, DOUGLAS FIR OR SOUTHERN PINE, SELECT, SAPWOOD WANTED FOR TREATMENT, WANE PERMITTED:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*A*, 22, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 11. BEAMS AND STRINGERS, SELECT, 85 % HEARTWOOD, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*C*, 21*B*.

No. 12. BEAMS AND STRINGERS, SELECT, NO HEARTWOOD OR SAPWOOD REQUIREMENT, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*C*.

No. 13. BEAMS AND STRINGERS, SELECT, NO HEARTWOOD OR SAPWOOD REQUIREMENT, WANE PERMITTED:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*A*.

No. 14. BEAMS AND STRINGERS, SELECT, SAPWOOD WANTED FOR TREATMENT, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*C*, 22.

No. 15. BEAMS AND STRINGERS, SELECT, SAPWOOD WANTED FOR TREATMENT, WANE PERMITTED:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 9 $(a + b)$, 15, 19*C*, 20*A*, 22.

Common Beams and Stringers

No. 16. BEAMS AND STRINGERS, COMMON, 85 % HEARTWOOD, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 10 $(a + b)$, 16, 19*D*, 20*C*, 21*B*.

No. 17. BEAMS AND STRINGERS, COMMON, NO HEARTWOOD OR SAPWOOD REQUIREMENT, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 10 $(a + b)$, 16, 19*D*, 20*C*.

No. 18. BEAMS AND STRINGERS, COMMON, NO HEARTWOOD OR SAPWOOD REQUIREMENT, WANE PERMITTED:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 10 $(a + b)$, 16, 19*D*, 20*B*.

No. 19. BEAMS AND STRINGERS, COMMON, SAPWOOD WANTED FOR TREATMENT, SQUARE EDGES:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 10 $(a + b)$, 16, 19*D*, 20*C*, 22.

No. 20. BEAMS AND STRINGERS, COMMON, SAPWOOD WANTED FOR TREATMENT, WANE PERMITTED:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 5 $(a + b + c + d + e)$, 10 $(a + b)$, 16, 19*D*, 20*B*, 22.

Dense Select Joist and Plank

No. 21. JOIST AND PLANK, DOUGLAS FIR OR SOUTHERN PINE, DENSE SELECT, 85 % HEARTWOOD, SQUARE EDGES:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$ 7, $(a + b + c)$, 13, 19*A*, 20*C*, 21*A*, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pines.

No. 22. JOIST AND PLANK, DOUGLAS FIR OR SOUTHERN PINE, DENSE SELECT, NO HEARTWOOD OR SAPWOOD REQUIREMENT, SQUARE EDGES:

1*A* (surfaced) or 1*C* (rough), 2, 3, $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*C*, 24, 25, 27, 28 $(a + b + c)$, Douglas fir or 29 $(a + b + c)$ southern pine.

No. 23. Joist and Plank, Douglas Fir or Southern Pine, Dense Select, No Heartwood or Sapwood Requirement, Wane Permitted:
A (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*A*, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$, southern pine.

No. 24. Joist and Plank, Douglas Fir or Southern Pine, Dense Select, Sapwood Wanted for Treatment, Square Edges:
A (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*C*, 22, 24, 25, 27, 28 $(a + b + c)$, Douglas fir or 29 $(a + b + c)$ southern pine.

No. 25. Joist and Plank, Douglas Fir or Southern Pine, Dense Select, Sapwood Wanted for Treatment, Wane Permitted:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*A*, 22, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

Select Joist and Plank

No. 26. Joist and Plank, Douglas Fir or Southern Pine, Select, 85 % Heartwood, Square Edges:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*C*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 27. Joist and Plank, Douglas Fir or Southern Pine, Select, No Heartwood or Sapwood Requirement, Square Edges:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*C*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 28. Joist and Plank, Douglas Fir or Southern Pine, Select, No Heartwood or Sapwood Requirement, Wane Permitted:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*A*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 29. Joist and Plank, Douglas Fir or Southern Pine, Select, Sapwood Wanted for Treatment, Square Edges:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*C*, 22, 23, 25, 26, 28, $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 30. Joist and Plank, Douglas Fir or Southern Pine, Select, Sapwood Wanted for Treatment, Wane Permitted:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*A*, 22, 23, 25, 26, 28 $(a + b + c)$, Douglas fir or 29 $(a + b + c)$ southern pine.

No. 31. Joist and Plank, Select, 85 % Heartwood, Square Edges:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*C*, 21*A*.

No. 32. Joist and Plank Select, No Heartwood or Sapwood Requirement, Square Edges:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*C*.

No. 33. Joist and Plank, Select, No Heartwood or Sapwood Requirement, Wane Permitted:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*A*.

No. 34. Joist and Plank, Select, Sapwood Wanted for Treatment, Square Edges:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*C*, 22.

No. 35. Joist and Plank, Select, Sapwood Wanted for Treatment, Wane Permitted:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 7 $(a + b + c)$, 13, 19*A*, 20*A*, 22.

Common Joist and Plank

No. 36. Joist and Plank, Common, 85 % Heartwood, Square Edges:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 8 $(a + b + c)$, 14, 19*B*, 20*C*, 21*A*.

No. 37. Joist and Plank, Common, No Heartwood or Sapwood Requirment, Square Edges:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 8 $(a + b + c)$, 14, 19*B*, 20*C*.

No. 38. Joist and Plank, Common, No Heartwood or Sapwood Requirement, Wane Permitted:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 8 $(a + b + c)$, 14, 19*B*, 20*B*.

No. 39. Joist and Plank, Common, Sapwood Wanted for Treatment, Square Edges:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 8 $(a + b + c)$, 14, 19*B*, 20*C*, 22.

No. 40. Joist and Plank, Common, Sapwood Wanted for Treatment, Wane Permitted:
1*A* (surfaced) or 1*C* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 4 $(a + b + c + d)$, 8 $(a + b + c)$, 14, 19*B*, 20*B*, 22.

Dense Select Posts and Timbers

No. 41. Posts and Timbers, Douglas Fir or Southern Pine, Dense Select, 85 % Heartwood, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11, $(a + b)$, 17, 19*E*, 20*C*, 21*C*, 24, 25, 27, 28 $(a + b + c)$, Douglas fir or 29 $(a + b + c)$ southern pine.

No. 42. Posts and Timbers, Douglas Fir or Southern Pine, Dense Select, No Heartwood or Sapwood Requirement, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 21*C*, 24, 25, 27, 28 $(a + b + c)$, Douglas fir or 29 $(a + b + c)$ southern pine.

No. 43. Posts and Timbers, Douglas Fir or Southern Pine, Dense Select, No Heartwood or Sapwood Requirement, Wane Permitted:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*A*, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 44. Posts and Timbers, Douglas Fir or Southern Pine, Dense Select, Sapwood Wanted for Treatment, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 22, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 45. Posts and Timbers, Douglas Fir or Southern Pine, Dense Select, Sapwood Wanted for Treatment, Wane Permitted:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*A*, 22, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

Select Posts and Timbers

No. 46. Posts and Timbers, Douglas Fir or Southern Pine, Select, 85 % Heartwood, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 21*C*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 47. Posts and Timbers, Douglas Fir or Southern Pine, Select, No Heartwood or Sapwood Requirement, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 48. Posts and Timbers, Douglas Fir or Southern Pine, Select, No Heartwood or Sapwood Requirement, Wane Permitted:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*A*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 49. Posts and Timbers, Douglas Fir or Southern Pine, Select, Sapwood Wanted for Treatment, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 22, 23, 25, 26, 28 $(a + b + c)$, Douglas fir, or 29 $(a + b + c)$ southern pine.

No. 50. Posts and Timbers, Douglas Fir or Southern Pine, Select, Sapwood Wanted for Treatment, Wane Permitted:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*A*, 22, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 51. Posts and Timbers, Select, 85 % Heartwood, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 21*C*.

No. 52. Posts and Timbers, Select, No Heartwood or Sapwood Requirement, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*.

No. 53. Posts and Timbers, Select, No Heartwood or Sapwood Requirement, Wane Permitted:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$ 17, 19*E*, 20*A*.

No. 54. Posts and Timbers, Select, Sapwood Wanted for Treatment, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 22.

No. 55. Posts and Timbers, Select, Sapwood Wanted for Treatment, Wane Permitted:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*A*, 22.

Common Posts and Timbers

No. 56. Posts and Timbers, Common, 85 % Heartwood, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 12 $(a + b)$, 18, 19*F*, 20*C*. 21*C*.

No. 57. Posts and Timbers, Common, No Heartwood or Sapwood Requirement, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 12 $(a + b)$, 18, 19*F*, 20*C*.

No. 58. Posts and Timbers, Common, No Heartwood or Sapwood Requirement, Wane Permitted:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 12 $(a + b)$, 18, 19*F*, 20*B*.

No. 59. Posts and Timbers, Common, Sapwood Wanted for Treatment, Square Edges:
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 12 $(a + b)$, 18, 19*F*, 20*C*, 22.

No. 60. Posts and Timbers, Common, Sapwood Wanted for Treatment, Wane Permitted.
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 12 $(a + b)$, 18, 19*F*, 20*B*, 22.

Special Posts and Timbers

No. 61. **Posts and Timbers, Douglas Fir or Southern Pine, Dense Select, One Narrow Face All Heartwood, Other Narrow Face and Sides 85 % Heartwood, Square Edges:**
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 21*D*, 24, 25, 27, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 62. **Posts and Timbers, Douglas Fir or Southern Pine, Select, One Narrow Face all Heartwood, Other Narrow Face and Sides 85 % Heartwood, Square Edges:**
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 21*D*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 63. **Posts and Timbers, Select, One Narrow Face All Heartwood, Other Narrow Face and Sides 85 % Heartwood, Square Edges:**
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11, $(a + b)$, 17, 19*E*, 20*C*, 21*D*.

No. 64. **Posts and Timbers, Common, One Narrow Face All Heartwood, Other Narrow Face and Sides 85 % Heartwood, Square Edges:**
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 12 $(a + b)$, 18, 19*F*, 20*C*, 21*D*.

No. 65. **Posts and Timbers, Douglas Fir or Southern Pine, Dense Select, One Narrow Face All Heartwood, Other Narrow Face and Sides 75 % Heartwood, Square Edges:**
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 21*E*, 24, 25, 27, 28 $(a + b + c)$ Douglas fir, or 29 $(a + b + c)$ southern pine.

No. 66. **Posts and Timbers, Douglas Fir or Southern Pine, Select, One Narrow Face All Heartwood, Other Narrow Face and Sides 75 % Heartwood, Square Edges:**
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 21*E*, 23, 25, 26, 28 $(a + b + c)$ Douglas fir or 29 $(a + b + c)$ southern pine.

No. 67. **Posts and Timbers, Select, One Narrow Face All Heartwood, Other Narrow Face and Sides 75 % Heartwood, Square Edges:**
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 11 $(a + b)$, 17, 19*E*, 20*C*, 21*E*.

No. 68. **Posts and Timbers, Common, One Narrow Face All Heartwood, Other Narrow Face and Sides, 75 % Heartwood, Square Edges:**
1*B* (surfaced) or 1*D* (rough), 2, 3 $(a + b + c + d + e + f + g + h + i)$, 6, 12 $(a + b)$, 18, 19*F*, 20*C*, 21*E*.

APPENDIX G

WORKING STRESSES FOR STRUCTURAL GRADES OF TIMBER[1]

Notes on Tables of Working Stresses

1. **Authority.**—The working stresses in the accompanying Table I are recommended by the Forest Products Laboratory, U. S. Forest Service, for structural grades complying with Basic Provisions for Structural Material of American Lumber Standards, including, also, stresses for red and white oak, as the same structural grades can be applied to hardwoods as to soft. In beam-and-stringer and post-and-timber grades, stresses are given only for the species commonly cut to those sizes. Stresses for any other species can be obtained from the Forest Products Laboratory.

2. **Minimum-strength Value.**—Structural grades are developed to ensure minimum strength values. The defects permitted in the common grades provide material having not less than 60 % of the strength of green clear wood, and in the select grades, of 75 %, although in Douglas fir and southern pine the stresses recommended in compression and in extreme fiber in bending are 80 % of green clear wood strength on account of the limitation on rate of growth.

3. **Exposure.**—Working values are given for three conditions of exposure during use: (*a*) continuously dry, (*b*) occasionally wet but quickly dried, (*c*) more or less continuously damp or wet. Judgment should be exercised as to the values to be used in a particular case.

(*a*) *Continuously Dry.*—Continuously dry contemplates use in interior or protected construction not subject to conditions of excessive dampness or high humidity.

(*b*) *Occasionally Wet.*—Occasionally wet but quickly dried assumes use in such exterior structures as bridges, trestles, grand stands or bleachers, and exposed framework of open sheds.

(*c*) *Usually Wet.*—More or less continuously damp or wet would apply to material exposed to waves or tidewater, or in contact with earth, or used in a building in portions that would be more or less continuously wet.

4. **Impact.**—The working values recommended may be used without allowance for impact up to 100 %.

5. **Maximum Horizontal Shear.**—Working values given for horizontal shear are maximum values. The maximum unit horizontal shear at any point in a beam as calculated is one and one-half of the average unit shear obtained by dividing the total shear at that point by the area of the cross-section.

6. **Analysis for Shear Stress.**—Recognition of all loads in designing for moving loads, or loads concentrated near a support, gives a calculated shearing stress higher than is actually developed. In calculating the shear at one end of a beam, the concentrated loads between that end and a point distant three times the depth of the beam from it may be considered as acting at that point. In moving loads, as on highway bridges or railway stringers, in computing the shear at one end it is safe to ignore all wheel loads between that end and a point three times the depth of the beam or stringer from it, when the balance of the span is assumed loaded so as to give a maximum shear stress.

[1] These data are published as the result of cooperative work by several organizations including the Forest Products Laboratory, the American Railway Engineering Association, and the A.S.T.M. They do not form a part of the specification as a purchase specification. They are printed with the specification as a convenience to the user so that the data will be immediately available without further reference.

TABLE I.—WORKING STRESSES FOR JOIST AND PLANK AND BEAMS AND STRINGERS,[1] POUNDS PER SQUARE INCH

For Material Complying with Structural Grades of the American Society for Testing Materials

Species	Extreme fiber in bending	Compression perpendicular to grain	Maximum horizontal shear	Modulus of elasticity
Continuously dry				
Select grade				
Cedar:				
Western red	900	200	80	1,000,000
Northern and southern white	750	175	70	800,000
Port Orford	1,100	250	90	1,200,000
Alaska	1,100	250	90	1,200,000
Cypress:				
Southern	1,300	350	100	1,200,000
Douglas fir:				
Coast region, Select	1,600	315	90	1,600,000
Dense select	1,750	380	105	1,600,000
Rocky Mountain region	1,100	275	85	1,200,000
Fir:				
Balsam	900	150	70	1,000,000
Golden, noble, silver, white	1,100	300	70	1,100,000
Hemlock:				
West Coast	1,300	300	75	1,400,000
Eastern	1,100	300	70	1,100,000
Larch:				
Western	1,200	325	100	1,300,000
Oak:				
Red and white	1,400	500	125	1,500,000
Pine:				
Southern, Select	1,600	345	110	1,600,000
Dense select	1,750	380	128	1,600,000
California, Idaho and Northern white, Pondosa and sugar	900	250	85	1,000,000
Norway	1,100	300	85	1,200,000
Redwood	1,200	250	70	1,200,000
Spruce:				
Red, white, Sitka	1,100	250	85	1,200,000
Engelmann	750	175	70	800,000
Tamarack:				
Eastern	1,200	300	95	1,300,000
Common grade				
Cedar:				
Western red	720	200	64	1,000,000
Northern and southern white	600	175	56	800,000
Port Orford	880	250	72	1,200,000
Alaska	880	250	72	1,200,000
Cypress:				
Southern	1,040	350	80	1,200,000
Douglas fir:				
Coast region	1,200	325	72	1,600,000
Rocky Mountain region	880	275	68	1,200,000
Fir:				
Balsam	720	150	56	1,000,000
Golden, noble, silver, white	880	300	56	1,100,000
Hemlock:				
West Coast	1,040	300	60	1,400,000
Eastern	880	300	56	1,100,000
Larch:				
Western	960	325	80	1,300,000
Oak:				
Red and white	1,120	500	100	1,500,000
Pine:				
Southern	1,200	325	88	1,600,000
California, Idaho and northern white, Pondosa, and sugar	720	250	68	1,000,000
Norway	880	300	68	1,200,000
Redwood	960	250	56	1,200,000
Spruce:				
Red, white, Sitka	880	250	68	1,200,000
Englemann	600	175	56	800,000
Tamarack:				
Eastern	960	300	76	1,300,000

TABLE I.—WORKING STRESSES (*Continued*)

Occasionally wet but quickly dried

Species	Extreme fiber in bending: 4 in. and thinner	Extreme fiber in bending: 5 in. and thicker	Compression perpendicular to grain	Maximum horizontal shear	Modulus of elasticity
Select grade					
Cedar:					
Western red	710	800	150	80	1,000,000
Northern and southern white	580	.....	140	70	800,000
Port Orford	890	1,000	200	90	1,200,000
Alaska	890	.....	200	90	1,200,000
Cypress:					
Southern	980	.....	250	100	1,200,000
Douglas fir:					
Coast region, select	1,240	1,385	240	90	1,600,000
Dense select	1,370	1,515	265	105	1,600,000
Rocky Mountain region	800	900	225	85	1,200,000
Fir:					
Balsam	670	....	125	70	1,000,000
Golden, noble, silver, white	800	.....	225	70	1,100,000
Hemlock:					
West Coast	980	1,100	225	75	1,400,000
Eastern	800	.....	225	70	1,100,000
Larch:					
Western	980	1,100	225	100	1,300,000
Oak:	1,070	1,200	375	125	1,500,000
Pine:					
Southern, select	1,240	1,385	240	110	1,600,000
Dense select	1,370	1,515	265	128	1,600,000
California, Idaho and northern white, Pondosa, and sugar	710	.....	150	85	1,000,000
Norway	890	..	175	85	1,200,000
Redwood	890	1,000	150	70	1,200,000
Spruce:					
Red, white, Sitka	800	900	150	85	1,200,000
Engelmann	580	.....	140	70	800,000
Tamarack:					
Eastern	980	. ..	225	95	1,300,000
Common grade					
Cedar:					
Western red	600	640	150	64	1,000,000
Northern and southern white	490	.....	140	56	800,000
Port Orford	760	800	200	72	1,200,000
Alaska	760	.....	200	72	1,200,000
Cypress:					
Southern	830	.....	250	80	1,200,000
Douglas fir:					
Coast region	980	1,040	225	72	1,600,000
Rocky Mountain region	680	720	225	68	1,200,000
Fir:					
Balsam	570	.....	125	56	1,000,000
Golden, noble, silver, white	680	.....	225	56	1,100,000
Hemlock:					
West Coast	830	880	225	60	1,400,000
Eastern	680	. . .	225	56	1,100,000
Larch:					
Western	830	880	225	80	1,300,000
Oak:					
Red and white	900	960	375	100	1,500,000
Pine:					
Southern	980	1,040	225	88	1,600,000
California, Idaho and northern white, Pondosa, and sugar	600	.....	150	68	1,000,000
Norway	760	.....	175	68	1,200,000
Redwood	760	800	150	56	1,200,000
Spruce:					
Red, White Sitka	680	720	150	68	1,200,000
Englemann	490	.....	140	56	800,000
Tamarack:					
Eastern	830	....	225	76	1,300,000

TABLE I.—WORKING STRESSES (*Continued*)

More or Less continuously damp or wet

Species	Extreme fiber in bending: 4 in. and thinner	Extreme fiber in bending: 5 in. and thicker	Compression perpendicular to grain	Maximum horizontal shear	Modulus of elasticity
Select grade					
Cedar:					
Western red	670	750	125	80	1,000,000
Northern and southern white	530	.....	100	70	800,000
Port Orford	800	900	150	90	1,200,000
Alaska	800	.....	150	90	1,200,000
Cypress:					
Southern	800	.....	225	100	1,200,000
Douglas fir:					
Coast region, select	950	1,065	215	90	1,600,000
Dense select	1,050	1,165	235	105	1,600,000
Rocky Mountain region	620	700	200	85	1,200,000
Fir:					
Balsam	530	....	100	70	1,000,000
Golden, noble, silver, white	710	..	200	70	1,100,000
Hemlock:					
West Coast	800	900	200	75	1,400,000
Eastern	710	.....	200	70	1,100,000
Larch:					
Western	800	900	200	100	1,300,000
Oak:					
Red and white	890	1,000	300	125	1,500,000
Pine:					
Southern, select	950	1,065	215	110	1,600,000
Dense select	1,050	1,165	235	128	1,600,000
California, Idaho and northern white Pondosa, and sugar	670	....	125	85	1,000,000
Norway	710	.....	150	85	1,200,000
Redwood	710	800	125	70	1,200,000
Spruce:					
Red, white, Sitka	710	800	125	85	1,200,000
Englemann	440	.....	100	70	800,000
Tamarack:					
Eastern	800	.....	200	95	1,300,000
Common grade					
Cedar:					
Western red	570	600	125	64	1,000,000
Northern and southern white	450	.....	100	56	800,000
Port Orford	680	720	150	72	1 200,000
Alaska	680	....	150	72	1,200,000
Cypress:					
Southern	680	.....	225	80	1,200,000
Douglas fir:					
Coast region	750	800	200	72	1,600 000
Rocky Mountain region	530	560	200	68	1,200,000
Fir:					
Balsam	450	.....	100	56	1,000,000
Golden, noble, silver, white	600	.....	200	56	1,100,000
Hemlock:					
West Coast	680	720	200	60	1,400,000
Eastern	600	.....	200	56	1,100,000
Larch:					
Western	680	720	200	80	1,300,000
Oak:					
Red and white	750	800	300	100	1,500,000
Pine:					
Southern	750	800	200	88	1,600,000
California, Idaho and northern white, Pondosa, and sugar	570	.....	125	68	1,000,000
Norway	600	.....	150	68	1,200,000
Redwood	600	640	125	56	1,200,000
Spruce:					
Red, white, Sitka	600	640	125	68	1,200,000
Englemann	370	.....	100	56	800,000
Tamarack:					
Eastern	680	.....	200	76	1,300,000

[1] Values are those recommended by Forest Products Laboratory, U. S. Forest Service.

7. Shear Stresses for Joint Details.—Shear stresses for joint details may be taken as 50 % greater than the values for horizontal shear given in Table I.

8. Permanent Set.—Timber constantly yields under long-continued loading, acquiring a permanent set. This set with a fully loaded beam is about equal to the deflection using the modulus of elasticity as given in the table. In order to minimize the results of sag, it is advisable to use values one-half those given in the tables.

9. Compression in Short Columns.—The working stresses for compression parallel to grain are for use on posts, struts, etc., with unsupported length not greater than ten times their least dimension. They are also for use in end bearing on compression members, as a short column or strut is more likely to fail at the end than at any other point in its length, and the variations in moisture content are greater there.

10. Compression in Medium-length Columns.—For columns of intermediate length, the Forest Products Laboratory finds from tests recently made that a fourth-power parabola, tangent to the Euler curve, is a conservative representation of the law controlling the strength. That is, from the short block to the long column in which the strength is dependent on stiffness, there is a falling off in ultimate strength which follows a smooth curve, very flat at first but curving sharply to become tangent to the Euler curve at two-thirds of the ultimate crushing strength.

11. Formula.—For columns from $\frac{P}{A} = S$ to $\frac{P}{A} = \frac{2S}{3}$,

$$\frac{P}{A} = S\left[1 - \frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]$$

where P = total load, pounds
A = area, square inches
$\frac{P}{A}$ = unit compressive stress
S = safe stress in compression parallel to grain for short columns
l = unsupported length, inches
d = least dimension, inches
E = modulus of elasticity
K = The $\frac{l}{d}$ at the point of tangency of the parabolic and Euler curves, at which $\frac{P}{A} = \frac{2S}{3}$. The value of K for any species and grade is $\frac{\pi}{2}\sqrt{\frac{E}{6S}}$

12. Influence of Defects.—The influence of defects on the compressive strength of columns of constant cross-section decreases as the length increases. When $\frac{l}{d}$ equals the value of K for the species and grade, defects such as are allowable in the grade have little influence on the strength as a column. Beyond this length the investigation of the strength of columns indicated that the Euler formula is quite accurate for long wooden columns with pin-end connections and that the maximum load is dependent upon stiffness. In such columns, a factor of safety of 3 should be applied to values of modulus of elasticity in order to obtain safe loading.

13. Influence of End Conditions.—The laboratory does not, with the present data and under ordinary conditions, find justification for increasing the stresses on square-end columns over those for carefully centered pin-end columns. Tests to determine the influence of end conditions are still being made, and it is probable that under special conditions higher stresses can be used.

14. Long Columns.—For long columns, with factor of safety of 3, $\frac{P}{A} = \frac{\pi^2}{36}\frac{E}{\left(\frac{l}{d}\right)^2}$

15. Maximum Length.—Columns should be limited in slenderness to $\frac{l}{d} = 50$.

16. Direct Tension—For direct tension the same values as for extreme fiber stress in bending may be used. Straight-grained wood has greater resistance to tension than to any other kind of stress. It has been found, however, practically impossible to design joints that will develop anywhere near the full tensile strength.

17. Joints and Beams in Direct Tension.—Grades of joists or beams may be used for members in direct tension, as in bottom chords of trusses, increase in size of defects toward ends being permissible because of the gradual application of stresses through splice plates or end connections.

18. Joist and Plank, Vertical or Horizontal.—The provisions of the joist-and-plank grades are such that working stresses for these grades may be applied to material used with wide faces vertical or horizontal. In material 5 in. and thicker with loads applied to the wide face, the knot requirements for this face are those for the narrow face as given in the rules.

19. Working Stresses in Timbers Nearly Square.—Where working stresses in bending are required for caps, bridge ties, etc., they should be graded on beam-and-stringer grades, but as such material is often square or has horizontal faces wider than the vertical faces, in contrast to beams and stringers in which the narrow faces are horizontal and the wide faces are vertical, care should be exercised that the knot limitations are applied to the proper faces.

20. Two-span Stringers.—In railway stringers of two spans' length, defects throughout the center two-thirds should be limited as in the center third of single-span stringers, for the maximum moment will be over the center support, and although the full positive moment would not be developed in either span so long as there was resistance

to negative moment over the center support, there might be circumstances in which full positive moment of resistance at the centers of the two spans would be desirable.

FACTORS OF SAFETY[1]

21. **Elastic Limit and Breaking Strength.**—In determining working stresses, the Forest Products Laboratory has considered both elastic limit and breaking strength. Elastic limit, however, is more variable and less definite than ultimate strength, and the latter is taken as the more dependable basis for the determination of safe working stresses.

22. **Factor of Safety.**—The factor of safety at a given working stress varies materially with the duration of the stress. At the recommended working stresses, given in the table for continuously dry locations, the average timber in buildings has a factor of safety of 6 on impact loading,[1] a factor of 4 or 5 min. loads and 2¼ for long-time loading, with a minimum factor of safety of 2 on 75 % of the pieces under long-time loading. About 1 piece in 100, of very light weight and with maximum defects for the grade, would be expected to break at one and one-half times the recommended stress under loading of approximately 10 years' duration. For new timbers in bridge construction, the factors of safety are about 15 % greater.

FACTORS AFFECTING WORKING STRESSES

23. **Basis of Working Strength.**—Working stresses are based on the length of the clear wood of the various species and, in some properties, on grade as fixed by limitation on size and location of knots, extent of shake and checks and extent of cross-grain, on conditions of exposure during use, and on size of piece. In southern pine and Douglas fir, working stresses in some properties are increased for limitation on rate of growth and for requirement of percentage of summerwood.

24. **Variations with Exposure, Grade, Size.**—Working stresses for extreme fiber in bending are varied with grade, extent of exposure, and size of piece; in horizontal shear, with grade; in compression parallel to grain, with grade and exposure; in compression perpendicular to grain, with exposure.

25. Working stresses in shear are not varied with size or extent of exposure; in compression parallel to grain they are not varied with size; in compression perpendicular to grain they are not varied with grade or size; in modulus of elasticity they are taken as the same in all grades.

26. **Rate of Growth and Density.**—In southern pine and Douglas fir, working stresses in extreme fiber in bending, compression parallel to grain, and compression perpendicular to grain, in any grade, may be increased one-fifteenth for material of close grain, or one-sixth for dense material, over material not so selected. Values in these species in shear may be increased one-sixth for dense material but not for limitation on rate of growth. Modulus of elasticity is not varied with these properties.

27. **Variations in Working Stresses.**—The several permitted working stresses vary with conditions as follows, a √ indicating that the stress varies, and a blank (.) indicating that the stress does not vary:

Property	Governing defects	Conditions of exposure	Grade	Size of piece	Rate of growth	Density
Extreme fiber stress in bending	Knots and angle of grain	√	√	√*	√	√
Horizontal shear	Shakes and checks	..	√	..	..	√
Compression parallel to grain	Knots and angle of grain	√	√	..	√	√
Compression perpendicular to grain	....	√	..	..	√	√
Modulus of elasticity	.. ..	..	..	..	..	..

* Dry location only.

[1] If impact stresses are neglected when less than 100 % of the live load producing them, the factor of safety for such loads will be reduced from 6 to a minimum of 3.

Table II.—Working Stresses for Posts and Timbers 6 × 6 in. and Larger,[1] Pounds per Square Inch

For Material Complying with Structural Grades of the American Society for Testing Materials

Species	Continuously dry — Compression parallel to grain, Ratio of length to least dimension (L/D): 10	12	14	16	18	20	25	30	35	40	50	Modulus of elasticity
Select grade												
Cedar:												
Western red	700	686	674	656	629	592	438	304	224	171	110	1,000,000
Douglas fir:												
Coast region, select	1,175	1,149	1,127	1,093	1,045	975	702	487	358	274	175	1,600,000
Dense select	1,285	1,251	1,222	1,176	1,112	1,022	702	487	358	274	175	1,600,000
Rocky mountain region	800	786	774	753	726	688	526	365	268	206	132	1,200,000
Hemlock:												
West Coast	900	885	872	852	823	783	614	426	313	240	153	1,400,000
Larch:												
Western	1,100	1,068	1,041	999	937	851	570	396	291	223	142	1,300,000
Oak:												
Red and white	1,000	982	967	943	908	860	658	457	336	257	164	1,500,000
Pine:												
Southern, select	1,175	1,149	1,127	1,093	1,045	975	702	487	358	274	175	1,600,000
Dense select	1,285	1,251	1,222	1,176	1,112	1,022	702	487	358	274	175	1,600,000
Redwood	1,000	972	917	910	856	781	526	365	268	206	132	1,200,000
Spruce												
Red, white, Sitka	800	786	771	753	720	688	526	365	268	206	132	1,200,000
Common grade												
Cedar:												
Western red	560	553	547	538	524	505	425	304	224	171	110	1,000,000
Douglas fir:												
Coast region	880	870	861	847	826	796	675	487	358	274	175	1,600,000
Rocky mountain region	640	632	627	617	602	582	500	365	268	206	132	1,200,000
Hemlock:												
West Coast	720	712	706	696	680	660	573	426	313	210	153	1,400,000
Larch:												
Western	880	863	849	828	798	752	570	396	291	223	142	1,300,000
Oak:												
Red and white	800	790	783	771	753	728	625	457	336	257	164	1,500,000
Pine:												
Southern	880	870	861	847	826	796	675	487	358	274	175	1,600,000
Redwood	800	786	773	754	726	688	526	365	268	206	132	1,200,000
Spruce:												
Red, white, Sitka	640	632	627	617	602	582	500	365	268	206	132	1,200,000

TABLE II.—WORKING STRESSES (*Continued*)

Species	Compression parallel to grain, Ratio of length to least dimension (L/D): 10	12	14	16	18	20	25	30	35	40	50	Modulus of elasticity
Posts and timbers 6 × 6 in. and larger — *Occasionally wet but quickly dried*												
Select grade												
Cedar:												
Western red	700	686	673	654	628	591	438	304	224	171	110	1,000,000
Douglas fir:												
Coast region, select	1,065	1,045	1,028	1,003	968	915	702	487	358	274	175	1,600,000
Dense select	1,165	1,139	1,118	1,083	1,036	971	702	487	358	274	175	1,600,000
Rocky mountain region	800	785	772	753	728	688	526	365	268	206	132	1,200,000
Hemlock:												
West Coast	900	885	871	851	824	783	612	426	313	240	153	1,400,000
Larch:												
Western	1,000	976	955	922	877	810	570	396	291	223	142	1,300,000
Oak:												
Red and white	900	886	876	859	834	798	652	457	336	257	164	1,500,000
Pine:												
Southern, select	1,065	1,045	1,028	1,003	968	915	702	487	358	274	175	1,600,000
Dense select	1,165	1,139	1,118	1,083	1,036	971	702	487	358	274	175	1,600,000
Redwood	900	879	861	834	794	738	526	365	268	206	132	1,200,000
Spruce:												
Red, white, Sitka	750	738	728	712	690	657	525	365	268	206	132	1,200,000
Common grade												
Cedar:												
Western red	560	552	546	537	523	504	425	304	224	171	110	1,000,000
Douglas fir:												
Coast region	800	792	781	773	758	736	644	487	358	274	175	1,600,000
Rocky mountain region	640	632	625	616	602	582	502	365	268	206	132	1,200,000
Hemlock:												
West Coast	720	712	705	695	681	659	572	426	313	240	153	1,400,000
Larch:												
Western	800	787	777	760	736	704	564	396	291	223	142	1,300,000
Oak:												
Red and white	720	714	708	698	686	668	592	457	336	257	164	1,500,000
Pine:												
Southern	800	792	781	773	758	736	644	487	358	274	175	1,600,000
Redwood:	720	709	700	685	666	637	518	365	268	206	132	1,200,000
Spruce:												
Red, white, Sitka	600	594	588	580	568	552	485	365	268	206	132	1,200,000

TABLE II.—WORKING STRESSES (*Continued*)

More or less continuously damp or wet												
	Compression parallel to grain Ratio of length to least dimension (L/D)											Modulus of elasticity
Species	10	12	14	16	18	20	25	30	35	40	50	
Select grade												
Cedar:												
Western, red	650	638	629	614	594	565	437	304	224	171	110	1,000,000
Douglas fir:												
Coast region, select	905	893	883	867	846	814	683	487	358	274	175	1,600,000
Dense select	990	974	961	940	910	871	698	487	358	274	175	1,600,000
Rocky mountain region	700	690	681	669	651	623	514	365	268	206	132	1,200,000
Hemlock:												
West Coast	800	789	780	766	745	717	600	426	313	240	153	1,400,000
Larch:												
Western	800	787	776	760	736	704	565	396	291	223	142	1,300,000
Oak:												
Red and white	800	790	783	771	753	728	625	457	336	257	164	1,500,000
Pine:												
Southern, select	905	893	883	867	846	814	683	487	358	274	175	1,600,000
Dense select	990	974	961	940	910	871	698	487	358	274	175	1,600,000
Redwood	750	737	727	712	690	657	525	365	268	206	132	1,200,000
Spruce:												
Red, white, Sitka	650	642	635	625	611	589	500	365	268	206	132	1,200,000
Common grade												
Cedar:												
Western red	520	514	509	502	491	475	413	304	224	171	110	1,000,000
Douglas fir:												
Coast region	680	675	670	664	655	641	588	482	358	274	175	1,600,000
Rocky mountain region	560	554	551	544	535	521	465	365	268	206	132	1,200,000
Hemlock:												
West Coast	640	634	629	622	612	598	537	426	313	240	153	1,400,000
Larch:												
Western	640	633	627	618	606	588	519	396	291	223	142	1,300,000
Oak:												
Red and white	640	636	631	625	616	603	550	453	336	257	164	1,500,000
Pine:												
Southern	680	675	670	664	655	641	588	482	358	274	175	1,600,000
Redwood	600	594	588	580	568	552	483	365	268	206	132	1,200,000
Spruce:												
Red, white, Sitka	520	515	512	507	500	489	446	365	268	206	132	1,200,000

[1] Values are those recommended by Forest Products Laboratory, U. S. Forest service.

SAFE LOADS FOR WOODEN COLUMNS

1. The unit working stresses in compression parallel to grain for columns whose ratio of unsupported length to least dimension does not exceed 10 shall be not greater than that given for the species in the accompanying Table II on working stresses.

2. For columns the ratio of whose unsupported length to least dimension is greater than 10, the following formula shall be used until the reduction in allowable stress equals one-third the stress for short columns:

$$\frac{P}{A} = S\left[1 - \frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]$$

where P = total loads, pounds
A = area, square inches
$\frac{P}{A}$ = unit compressive stress
S = safe stress in compression parallel to grain for short columns
l = unsupported length, inches
d = least dimension, inches
E = modulus of elasticity
K = the $\frac{l}{d}$ at the point of tangency of the parabolic and Euler curves, at which $\frac{P}{A} = \frac{2}{3}S$

The value of K for any species and grade is $\frac{\pi}{2}\sqrt{\frac{E}{6S}}$.

3. For columns of greater length, the Euler formula below, which includes a factor of safety of 3, shall be used:

$$\frac{P}{A} = \frac{\pi^2}{36} \frac{E}{\left(\frac{l}{d}\right)^2}$$

4. Columns shall be limited in slenderness to $\frac{l}{d} = 50$.

Values of K for Columns of Intermediate Length

Species	Continuously dry		Occasionally wet		Usually wet	
	Select	Common	Select	Common	Select	Common
Cedar:						
Western red	24.2	27.1	24.2	27.1	25.1	28.1
Cedar:						
Port Orford	23.4	26.2	24.6	27.4	25.6	28.7
Douglas fir:						
Coast region, select	23.7	27.3	24.9	28.6	27.0	31.1
Dense select	22.6	24.9	23.8	26.1	25.8	28.3
Rocky Mountain region	24.8	27.8	24.8	27.8	26.5	29.7
Hemlock:						
West Coast	25.3	28.3	25.3	28.3	26.8	30.0
Larch:						
Western	22.0	24.6	23.1	25.8	25.8	28.8
Oak:						
Red and white	24.8	27.8	26.1	29.3	27.7	31.1
Pine, southern, select	23.7	27.3	24.9	28.6	27.0	31.1
Dense select	22.6	24.9	23.8	26.1	25.8	28.3
Redwood	22.2	24.8	23.4	26.1	25.6	28.6
Spruce:						
Red, white, Sitka	24.8	27.8	25.6	28.7	27.5	30.8

Strength of Columns of Intermediate Length, Expressed as a Percentage of Strength of Short Columns

Values for the expression $\left[1 - \frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]$ in the formula: $\frac{P}{A} = S\left[1 - \frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]$

	Ratio of length to least dimension in rectangular timbers $\frac{l}{d}$																		
K	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
22	97	96	95	93	91	88	85	81	77	72	67									
23	98	97	95	94	92	90	87	84	81	77	72	67								
24	98	97	96	95	93	92	89	87	84	80	76	72	67							
25	98	98	97	96	94	93	91	89	86	83	80	76	72	67						
26	99	98	97	96	95	93	92	91	89	86	83	80	74	72	67					
27	99	98	98	97	96	95	93	92	90	88	85	82	79	74	71	67				
28	99	98	98	97	96	95	94	93	91	89	87	85	82	79	75	71	67			
29	99	99	98	98	97	96	95	94	92	91	89	87	84	82	79	75	71	67		
30	99	99	98	98	97	97	96	95	94	92	90	88	86	84	81	78	75	71	67	
31	99	99	99	98	98	97	96	95	94	93	92	90	88	86	84	81	78	75	71	67

Note.—This table can also be used for columns not rectangular, the l/d being equivalent to $0.289\ l/r$, where is the least radius of gyration of the section.

APPENDIX H

TESTS ON BRICK PIERS

The most important tests on brick piers of recent years were made by J. G. Bragg of the Bureau of Standards, the tests being conducted with the cooperation of the National Brick Manufacturers' Association. The 50 piers tested were 30 in. square and were of a height of 10 ft., except 4 piers reinforced with wire mesh which were 5 ft. The bricks were selected from the districts of Chicago, Pittsburgh, New York, and New Orleans. They were classified as (1) hard burned best quality, (2) medium burned or common, and (3) soft burned or inferior quality. The mortars, bonding, and other data of the tests of piers and individual bricks are given in Technologic Paper No. 111, Bureau of Standards. The accompanying table which is self-explanatory is quoted therefrom.

DETAILS OF CONSTRUCTION AND SUMMARY OF TEST DATA. (Piers of Main Investigation)
Pittsburgh District, Cement Mortar

	Piers										Bricks: Test data			
	Construction data					Test data								
Serial number	Grade of bricks*	Bond: Header and stretcher**	Courses	Mortar	Height (ft.)	Age in days	Area (sq. in.)	Maximum load (lb.)	Maximum load (lb. per sq. in.)	Modulus of elasticity	Average compressive strength, flat (10 tests)	Average compressive strength on edge (10 tests)	Average transverse strength, modulus of rupture (20 tests)[1]	Per cent. of absorption on samples in compression tests[1]
1	1	1:1	46	1 cement; 3 sand	10	30	930	2,520,000	2,710	2,500,000	11,990	8,900	1,945	4.08
2	1	1:3	46	1 cement; 3 sand	10	30	930	2,550,000	2,740	3,200,000	11,990	8,900	1,945	4.08
3	1	1:6	46	1 cement; 3 sand	10	30	930	2,697,000	2,900	3,200,000	11,990	8,900	1,945	4.08
4	2	1:1	45	1 cement; 3 sand	10	32	856	1,714,000	2,000	2,250,000	7,880	6,450	1,370	7.46
5	2	1:3	45	1 cement; 3 sand	10	32	885	1,834,000	2,070	2,000,000	7,880	6,450	1,370	7.46
6	2	1:6	44	1 cement; 3 sand	10	33	946	824,000	870	833,000	2,450	2,040	675	15.16
7	3	1:1	41	1 cement; 3 sand	10	29	1,024	524,000	510	700,000	1,659	1,350	345	16.28
8	3	1:3	41	1 cement; 3 sand	10	29	1,043	580,000	560	733,000	1,659	1,350	345	16.28
9	3	1:6	41	1 cement; 3 sand	10	32	1,024	660,000	650	533,000	1,659	1,350	345	16.28
	Pittsburgh District, Cement and Lime Mortar													
10	1	1:1	45	1 (15% lime, 85% cement); 3 sand	10	90	841	3,211,000	3,800	3,500,000	11,965	10,050	2,775	1.28
11	1	1:3	45	1 (15% lime, 85% cement); 3 sand	10	90	841	2,714,000	3,220	3,050,000	11,965	10,050	2,775	1.28
12	1	1:6	45	1 (15% lime, 85% cement;) 3 sand	10	90	841	2,787,000	3,300	3,500,000	11,965	10,050	2,775	1.28
13	2	1:1	45	1 (15% lime, 85% cement); 3 sand	10	33	908	1,594,000	1,760	1,550,000	7,880	6,450	1,370	7.46
14	2	1:3	44	1 (15% lime, 85% cement); 3 sand	10	32	961	838,000	870	750,000	2,450	2,040	675	15.16
15	2	1:6	45	1 (15% lime, 85% cement); 3 sand	10	30	878	1,545,800	1,760	1,625,000	7,880	6,450	1,370	7.46

*, **, [1] See p. 1524.

Details of Construction and Summary of Test Data. (Piers of Main Investigation)—*Continued*

Pittsburgh District, Lime Mortar

Serial number	Piers: Construction data: Grade of bricks*	Bond: Header and stretcher**	Courses	Mortar	Height (ft.)	Piers: Test data: Age in days	Area (sq. in.)	Maximum load (lb.)	Maximum load (lb. per sq. in.)	Modulus of elasticity	Bricks: Test data: Average compressive strength, flat (10 tests)	Average compressive strength on edge (10 tests)	Average transverse strength, modulus of rupture (20 tests)[1]	Per cent. of absorption on samples in compression tests
16	1	1:1	45	1 lime; 6 sand.....	10	120	940	1,360,000	1,450	725,000	11,990	8,900	1,945	4.08
17	1	1:3	45	1 lime; 6 sand. ...	10	120	940	1,197,500	1,270	416,700	11,990	8,900	1,945	4.08
18	1	1:6	45	1 lime; 6 sand.....	10	120	940	1,280,000	1,360	750,000	11,990	8,900	1,945	4.08
19	2	1:1	44	1 lime; 6 sand....	10	120	906	764,000	840	620,000	7,800	6,450	1,370	7.46
20	2	1:3	44	1 lime; 6 sand....	10	120	906	804,000	890	687,000	7,880	6,450	1,370	7.46
21	2	1:6	44	1 lime; 6 sand....	10	120	900	892,000	990	620,000	7,880	6,450	1,370	7.46
22	3	1:1	41	1 lime; 3 sand....	10	120	1,024	215,500	210	300,000	1,659	1,350	345	16.28
23	3	1:3	41	1 lime; 3 sand.....	10	120	1,024	182,000	178	300,000	1,659	1,350	345	16.28
24	3	1:6	41	1 lime; 3 sand.....	10	120	1,024	129,000	126	270,000	1,659	1,350	345	16.28
				New Orleans District, Cement and Lime Mortar										
25	1	1:1	41	1 (15% lime, 85% cement); 3 sand	10	29	841	1,223,000	1,450	1,533,000	7,340	4,910	733	16.80
26	1	1:3	41	1 (15% lime, 85% cement); 3 sand	10	29	841	1,475,000	1,760	1,533,000	7,340	4,910	733	16.80
27	2	1:1	41	1 (15% lime, 85% cement); 3 sand	10	31	841	1,370,000	1,630	1,563,000	6,880	5,490	893	16.40
28	2	1:3	41	1 (15% lime, 85% cement); 3 sand	10	30	841	1,506,000	1,790	1,750,000	6,880	5,490	893	16.40
29	3	1:1	41	1 (15% lime, 85% cement); 3 sand	10	30	841	1,580,000	1,880	1,833,000	6,510	5,700	1,090	17.10
30	3	1:3	41	1 (15% lime, 85% cement); 3 sand	10	29	841	1,422,000	1,690	1,583,000	6,510	5,700	1,090	17.10
31	3	1:6	41	1 (15% lime, 85% cement); 3 sand	10	31	841	1,397,000	1,660	1,583,000	6,510	5,700	1,090	17.10

DETAILS OF CONSTRUCTION AND SUMMARY OF TEST DATA. (Piers of Main Investigation)—*Continued*

New York District, Cement and Lime Mortar

Serial number	Piers: Construction data: Grade of bricks*	Bond: Header and stretcher**	Courses	Mortar	Height (ft.)	Piers: Test data: Age in days	Area (sq. in.)	Maximum load (lb.)	Maximum load (lb. per sq. in.)	Modulus of elasticity	Bricks: Test data: Average compressive strength, flat (10 tests)	Average compressive strength on edge (10 tests)	Average transverse strength, modulus of rupture (20 tests)[1]	Per cent of absorption on samples in compression tests
32	1	1:1	45	1(15 % line, 85 % cement); 3 sand	10	32	791	921,500	1,170	875,000	5,630	6,440	601	16.40
33	1	1:3	45	1 (15 % lime, 85 % cement); 3 sand	10	32	791	1,033,500	1,300	875,000	5,630	6,440	601	16.40
34	1	1:6	45	1 (15 % lime 85 % cement); 3 sand	10	31	791	998,000	1,260	875,000	5,630	6,440	601	16.40
35	2	1:1	45	1 (15 % lime, 85 % cement); 3 sand	10	30	784	1,001,000	1,280	875,000	4,430	5,449	616	18.60
36	2	1:3	45	1 (15 % lime, 85 % cement); 3 sand	10	31	791	1,011,000	1,280	1,125,000	4,430	5,449	616	18.60
37	2	1:6	45	1 (15 % lime, 85 % cement); 3 sand	10	31	791	967,500	1,220	817,000	4,430	5,449	616	18.60
38	3	1:1	45	1 (15 % lime, 85 % cement); 3 sand	10	31	791	840,500	1,070	484,000	2,710	2,970	497	19.30
39	3	1:3	45	1 (15 % lime, 85 % cement); 3 sand	10	31	791	840,000	1,060	667,000	2,710	2,970	497	19.30
40	3	1:6	45	1 (15 % lime, 85 % cement); 3 sand	10	30	791	808,000	1,020	600,000	2,710	2,970	497	19.30
Chicago District, Cement and Lime Mortar														
41	1	1:1	46	1 (15 % lime, 85 % cement). 3 sand	10	32	841	706,700	840	833,000	3,200	3,010	1,180	16.20
42	1	1:3	46	1 (15 % lime, 85 % cement); 3 sand	10	29	812	641,500	790	750,000	3,200	3,010	1,180	16.20
43	1	1:6	46	1 (15 % lime, 85 % cement); 3 sand	10	30	812	660,500	810	750,000	3,200	3,010	1,180	16.20
44	2	1:1	46	1 (15 % lime, 85 % cement); 3 sand	10	30	812	606,500	750	833,000	3,150	2,710	1,140	16.20
45	2	1:3	46	1 (15 % lime, 85 % cement); 3 sand	10	30	812	572,000	700	650,000	3,150	2,710	1,140	16.20
46	2	1:6	46	1 (15 % lime, 85 % cement); 3 sand	10	30	812	578,500	710	580,000	3,150	2,710	1,140	16.20

DETAILS OF CONSTRUCTION AND SUMMARY OF TEST DATA. (Supplementary Piers)

Serial number	Piers									Bricks: Test data			
	Construction data			Test data									
	Grade of brick	Type of bond	Mortar	Height (ft.)	Age in days	Area (sq. in.)	Maximum load (lb.)	Maximum load lb. per sq. in.)	Per cent. increase or decrease in strength	Average com-pressive strength, flat	Average com-pressive strength on edge	Average trans-verse strength modulus of rupture	Per cent of ab-sorption
47	2	1 header, type (a), Fig. 1, to 1 stretcher.	1 (15% lime, 85% cement); to 3 sand.	5	30	915	1,580,000	1,730	0	2,450	2,040	675	15.16
48	2	1 header, type (c), Fig. 1, to 1 stretcher.	1 (15% lime, 85% cement); to 3 sand.	5	30	915	1,678,000	1,840	+6.4	2,450	2,040	675	15.16
49	2	Same as No. 47, with 18 gage No. 2 galvanized-iron wire mesh in every joint.	1 (15% lime, 85% cement); to 3 sand.	5	30	924	2,100,000	2,270	+31.2	2,450	2,040	675	15.16
50	2	Same as No. 47, with 18 gage No. 2 galvanized-iron wire mesh in every fourth joint.	1 (15% lime, 85% cement); to 3 sand.	5	30	930	1,364,000	1,470	−15.0	2,450	2,040	675	15.19

* 1 = best hard burned; 2 = medium burned; 3 = soft burned, inferior qualities.

** 1:1 = alternate headers and stretchers, "squeeze" joints.
1:3 = 1 course headers, 3 stretchers, filled joints without "squeezing."
1:6 = 1 course headers, 6 stretchers, "slushed" joints.

[1] Ten tests only were made in case of Grade 3 from the Pittsburgh District.

A summary is also submitted in Technologic Paper No. 111 of the results of Tests by Howard, McCausland, MacGregor, and Kreuger as follows:

Howard's Tests (Eng. Rec., March 22, 1913).—This work consists of several series of pier tests, in which a study was made of various mortars, grades of brick, and methods of laying the bricks. A novel feature of this work was the laying of bricks on edge and in some case breaking joints every third or sixth course, instead of every course. The piers tested ranged in cross-sectional dimensions from 8 × 8 in to 16 × 16 in., the heights varying from 2 to 12 ft. 6 in. In these tests, 14 of which were made on face-brick piers laid in 1 part Rosendale cement to 2 parts sand mortar, the strength was found to vary with the height of pier, the ultimate resistance of the pier varying from 12 5 to 18.1% of the compressive strength of the bricks. Thirty-eight common-brick piers of the same mortar and general dimensions developed a strength of from 7.8 to 17.6% of the compressive strength of the bricks. Laying the bricks on edge and breaking joints every third or sixth course increased the strength considerably.

Results of some of these tests are given in the following table which is taken from Burr's Elasticity and Resistance of the Materials of Engineering, sixth edition:

CRUSHING STRENGTH OF BRICK PIERS OF VARIOUS SIZES LAID IN DIFFERENT MORTARS

No.	Height of pier	Section of pier (inches)	Composition of mortar	Weight per cubic foot (pounds)	Ultimate resistance (lb. per sq. in.)
a1	1 ft. 4 in.	8 × 8	1 lime, 3 sand	137.4	2520
a2	6 ft. 8 in.	8 × 8	1 lime, 3 sand	133.5	1877
a3	1 ft. 4 in.	8 × 8	1 Portland cement, 3 sand	136.3	3776
a4	6 ft. 8 in.	8 × 8	1 Portland cement, 3 sand	135.5	2249
a5	2 ft. 0 in.	12 × 12	1 lime, 3 sand	.....	1940
a6	2 ft. 0 in.	12 × 12	1 lime, 3 sand	.....	1900
a7	10 ft. 0 in.	12 × 12	1 lime, 3 sand	131.7	1511
a8	10 ft. 0 in.	12 × 12	1 lime, 3 sand	125.0	1807
a9	2 ft. 0 in.	12 × 12	1 Portland cement, 2 sand	.....	3670
a10	10 ft. 0 in.	12 × 12	1 Portland cement, 2 sand	132.2	2253
b11	1 ft. 4 in.	8 × 8	1 lime, 3 sand	135.6	2440
b12	6 ft. 8 in.	8 × 8	1 lime, 3 sand	133.6	1540
b13	2 ft. 0 in.	12 × 12	1 lime, 3 sand	....	2150
b14	2 ft. 0 in.	12 × 12	1 lime, 3 sand	.....	2050
b15	9 ft. 9 in.	12 × 12	1 lime, 3 sand	131.5	1118
b16	10 ft. 0 in.	12 × 12	1 lime, 3 sand	136.0	1587
b17	10 ft. 0 in.	12 × 12	1 Portland cement, 2 sand	131.0	2003
b18	2 ft. 0 in.	16 × 16	1 Portland cement, 2 sand	.....	2720
b19	10 ft. 0 in.	16 × 16	1 Portland cement, 2 sand	....	1887

a. The kind of brick used in this test was face brick, with an average compressive strength of 13,925 lb. per sq. in.

b. The kind of brick used in this test was common brick, with an average compressive strength of 18,337 lb. per sq. in.

McCaustland's Tests (Transactions of the Association of Civil Engineering of Cornell University for 1900).—This investigation was composed of a series of 14 piers, 13 × 13 in. in cross-sectional dimensions and 80 in. high, which were reinforced laterally in the horizontal joints with steel plates, straps, or wire meshing. The mortar was composed of 1 part Portland cement and 3 parts sand. The bricks used had a compressive strength of 3500 lb. per sq. in. In these tests it is shown that the efficiencies of the piers reinforced with iron straps and plates are less than those of the piers without reinforcement. The piers reinforced with wire mesh in every joint developed efficiencies of 46% as compared with 30% for those without reinforcement. However, there is a considerable drop in efficiency from the piers with wire mesh in every joint and piers with wire mesh in every second joint, which developed efficiencies of only 33 %.

The table of results of McCaustland's tests, given on page 1526, is taken from Burr's Elasticity and Resistance of the Materials of Engineering, sixth edition:

Macgregor's Tests (Tests made by Prof. J. S. Macgregor, Columbia University).—The object of this investigation was to ascertain what proportions of cement and lime may be used to advantage in a cement-lime mortar and the effect of such mortars on the ultimate compressive strength of brick masonry. Seven sets of brick piers 8 × 8× 84 in. were tested. Each set of 9 piers represented a different proportion of mortar with varying amounts of hydrated lime. Each set was composed of 3 groups of 3 piers each, group 1 being tested at 7 days, group 2 at 28 days, and group 3 at 90 days. The bricks used were hard-burned face bricks. There were also tested 7 piers of common brick, one for each different mortar. These piers served as a check on the hard-burned face brick piers, and were tested at the age of 28 days. In these tests piers laid in a mortar composed of 1 part (25% lime and 75% Portland cement) to 3 parts sand by volume developed the highest strength. Piers laid in mortar composed of

ULTIMATE COMPRESSIVE RESISTANCE OF 13 × 13 × 80-in. BRICK PIERS WITH METAL REINFORCEMENT IN HORIZONTAL JOINTS

(Built with 1 : 2 Portland cement mortar; joints 0.3 in. thick)

No.	Kinds of joints	Ultimate stress: Total	Ultimate stress: Pounds per square inch	Efficiency per cent. of single brick
1	Portland-cement mortar, 1:2. . . .	194,000	1,150	30
2	Portland-cement mortar, 1.2.	200,000	1,184	
3	Iron straps every fourth course	136,400	810	24
4	Iron straps every fourth course.	155,400	920	
5	Iron straps every sixth course.	130,000	780	22
6	Iron straps every eighth course . . .	142,500	843	24
7	Iron netting every second course	192,000	1,136	33
8	Iron netting every second course	208,000	1,218	
9	Wire netting every course.	282,000	1,694	40
10	Wire netting every course.	240,000	1,140	
11	Iron plate every fourth course.	174,000	1,030	28
12	Iron plate every fourth course.	193,500	1,145	
13	Iron plate every fourth course. . . .	162,000	974	
14	Iron plate every fourth course.	143,000	858	

1 part (50% lime and 50% Portland cement) to 3 parts sand developed higher strengths than piers laid in 1 part cement to 3 parts sand mortar.

The following data are taken from Bulletin J, Hydrated Lime Bureau of the National Lime Manufacturers' Association:

EFFECT OF CEMENT-LIME MORTAR ON STRENGTH OF 8 × 8-in. BRICK PIERS

Mortar mixture used: By volume	Mortar mixture used: By weight	Age when tested (days)	Compressive strength (lb. per sq. in.): Face-brick piers; each result an average of 3 tests	Compressive strength (lb. per sq. in.): Common-brick piers; 1 test only
		7	2630	
1 Portland cement; 3 sand. . .	100 Portland cement; 300	28	2840	1170
	sand.	90	2840	
0.90 Portland cement.	90 Portland cement. . .	7	3080	
0.10 hydrated lime.	4 hydrated lime.	28	3170	1189
3 sand	300 sand.	90	4135	
0.85 Portland cement. . . .	85 Portland cement. .	7	2890	
0.15 hydrated lime.	6 hydrated lime.	28	3230	1340
3 sand.	300 sand.	90	4300	
0.75 Portland cement .	75 Portland cement.	7	3120	
0.25 hydrated lime.	10 hydrated lime.	28	3470	1685
3 sand.	300 sand.	90	4170	
0.50 Portland cement. . . .	50 Portland cement.	7	2760	
0.50 hydrated lime.	20 hydrated lime.	28	3100	1300
3 sand.	300 sand.	90	3820	
0.25 Portland cement.	25 Portland cement.	7	1945	
0.75 hydrated lime.	30 hydrated lime.	28	2370	1032
3 sand.	300 sand.	90	2720	
1 hydrated lime.	40 hydrated lime.	7	1535	
3 sand.	300 sand.	28	1870	
		90	1950	

Kreuger's Tests **(Clay Worker, July 1916, and August 1916).—A recent investigation by Prof. H. Kreuger at the Technical High School in Stockholm, although conducted on small piers, is quite comprehensive in its scope. This investigation includes most of the variables referred to in previous tests and some tests were made to study the effect of eccentric loading. The piers tested were approximately 11 in. square, ranging in height from 0 to 33 in. With bricks of various strengths laid in 1 part lime to 3 part sand mortar, the piers developed strengths of from 18.5 to 26.5% of the ultimate compressive strength of bricks. It must be noted, however, that the results obtained by Prof. Kreuger are not comparable with results of tests made in the United States, since the method of testing the individual bricks is different. Prof. Kreuger's results were obtained from compression tests on halves of the same brick cemented together. Since the compressive strength developed in this manner would be considerably lower than in the case of a single half brick tested flat, the efficiency of the pier would be correspondingly higher. Tests of the mortar used showed an increase in strength from 28 days to 1 year of 33 to 165%, while the piers increased in strength in the same length of time only 6 to 17%. The introduction of wire mesh in every joint increased the strength 88 to 100%. Piers loaded eccentrically on one-half their bearing surfaces failed at loads slightly under one-half the loads sustained by piers loaded concentrically, and no cracking was observed on the so-called tension side of the pier.**

The following data are taken from the Clay Worker for July 1917 and August 1917. The results have been converted from the metric to the English units of measure and retabulated.

INFLUENCE OF THE STRENGTH OF BRICK
(Mortar: 1 lime, 3 sand; age: 28 days)

No. of piers tested	Height of piers (inches)	Breadth of piers (inches)	Average compressive strength (lb. per sq. in.)		% of compressive strength of bricks developed in piers		
			Bricks used	Piers	Minimum	Maximum	Average
5	31.0	10.0	1920	410	19.3	23.7	21.3
4	31.0	9.5	2510	670	23.7	29.5	26.5
3	33.0	9.5	4040	880	20.0	24.3	21.8
5	33.5	9.5	5300	980	15.0	21.2	18.5
4	31.0	9.5	7120	1820	24.7	26.2	25.5
5	30.5	9.0	8600	1680	17.5	21.6	19.5

INFLUENCE OF THE STRENGTH OF MORTAR
(Mortar: 1 lime, 3 sand; age: 28 days)

Pier No.	Compressive strength (lb. per sq. in.)		Mortar mixture	Compressive strength (lb. per sq. in.)
	Bricks	Mortar		
1	4040	0	Dry sand	740
2	4040	38	1 lime; 3 sand	740
3	4040	355	2 lime; 1 cement; 9 sand	1420
4	4040	695	1 lime; 1 cement; 6 sand	1840
5	4040	1280	1 lime; 2 cement; 9 sand	1700
6	4040	1640	2 lime; 1 cement; 7 sand	1930
7	4040	2620	1 cement; 3 sand	1980

Influence of Varying the Height of the Piers
(Mortar: 1 lime, 3 sand)

Pier no.	Compressive strength of bricks (lb. per sq. in.)	Breadth of pier (inches)	Ratio of height to breadth	Compressive strength of piers (lb. per sq. in.)
1	3260	10.6	4.3	2340
2	3260	10.6	8.7	2320
3	3260	10.6	13.0	1940
4	3260	10.6	17.4	1620
5	3260	10.6	21.7	1090
6	3260	10.6	26.4	1020
7	3260	10.6	30.7	Broke
8	3260	10.6	35.4	780
9	3260	10.6	39.5	880
10	3260	10.6	43.4	880
11	3260	10.6	42.8	750
12	3260	10.6	53.2	780
13	3260	10.6	57.5	640
14	3260	10.6	61.8	610
15	3260	10.6	65.8	660
16	3260	10.6	69.7	660
17	3260	10.6	74.5	610
18	3260	10.6	78.8	610

Effect of Eccentric Loading
(Mortar: 1 lime, 3 sand)

Height of pier (inches)	Breadth of pier (inches)	Compressive strength of brick (lb. per sq. in.)	Compressive strength of mortar (lb. per sq. in.)	Maximum load	
				Concentric load (lb. per sq. in.)	Eccentric load (lb. per sq. in.)
33	9.4	4040	50	890	417
33	9.4	5600	50	1220	570
31	9.4	7100	50	1850	850

Tests made by the Bureau of Standards on 2 piers, 4 ft. square by 12 ft. high, brick common hard burned, laid in 1:1 cement mortar, ages of piers 31 and 57 days, developed compressive strengths of 6,580,000 and 1,710,000 lb. respectively (*Eng. Record*, March 22, 1913).

Other information on tests of brick piers and bricks will be found in U. S. Rep. Tests of Metals 1884–6, Trans. Assoc. C. E. Cornell Univ. 1900, Burr's Elas. and Resist. of Mat., Johnson's Mat. of Construction, Baker's Masonry, Clay Worker July–August 1916, and Mar. 1913. Refer to Amer. Soc. Test. Mat. Rep. of Comm. 6–3, Vol. 15, 915 for numerous tests on building brick from various locations.

APPENDIX I

STRENGTH OF STONE MASONRY

With most stones commonly used in building construction, the strength of the stone itself is far greater than any distributed load that will be imposed upon it. Any limitations of strength are therefore imposed either (1) through faulty and uneven bedding, or (2) through the lower strength of mortar in which the stones are set.

Such cases of failure of stone masonry as are on record indicate that failure was by tension of flexure, induced by squeezing out of mortar from joints, rather than in compression. No experimental data has been obtained except on relatively small brick piers (see Appendix *H*), but these tests indicate that the mortar was in each case the weak element of the combination; and that an increase of 50% in the strength of the brick produced no increase of strength in the structure, while substitution of cement for lime mortar increased the strength 70%.

Allowable Pressures on Stone Masonry.—The following data on foundation pressures on masonry are cited in Baker's Treatise on Masonry Construction:

"Early builders used much more massive masonry, proportional to the load to be carried, than is customary at present. Experience and experiments have shown that such great strength is unnecessary. The load on the monolithic piers supporting the large churches in Europe does not usually exceed 30 tons per sq. ft. (420 lb. per sq. in.), or about one-thirtieth of the ultimate strength of the stone alone, although the columns of the Church of All Saints at Angers, France, are said to sustain 43 tons per sq. ft. (600 lb per sq. in.). The stone-arch bridge of 140 ft. span at Pont-y-Pyrdd, over the Taff, in Wales, erected in 1750, is supposed to have a pressure of 72 tons per sq. ft. (1000 lb. per sq. in.) on hard limestone rubble masonry laid in lime mortar. The granite piers of the Saltash Bridge sustain a pressure of 9 tons per sq. ft. (125 lb. per sq. in.).

"The maximum pressure on the granite masonry of the towers of the Brooklyn Bridge is about 28½ tons per sq. ft. (about 400 lb. per sq. in.). The maximum pressure on the limestone masonry of this bridge is about 10 tons per sq ft. (125 lb. per sq. in.). The face stones ranged in cubical contents from 1½ to 5 cu. yd.; the stones of the granite backing averaged about 1½ cu. yd., and of the limestone about 1¼ cu yd. per piece. The mortar was 1 volume of Rosendale natural cement and 2 of sand. The stones were rough-axed or pointed to ½-in. bed-joints and ½-in. vertical face-joints.

"In the Rookery Building, Chicago, granite columns about 3 ft. square sustain 30 tons per sq. ft. (415 lb. per sq. in.) without any signs of weakness.

"In the Washington Monument, Washington, D. C., the normal pressure on the lower joint of the walls of the shaft is 20.2 tons per sq. ft. (280 lb. per sq. in.), and the maximum pressure brought upon any joint under the action of the wind is 25.4 tons per sq. ft. (350 lb. per sq. in.).

"The pressure on the limestone piers of the St. Louis Bridge was, before completion, 38 tons per sq. ft. (527 lb. per sq. in.); and after completion the pressure was 19 tons per sq. ft (273) lb. per sq. in.) on the piers and 15 tons per sq. ft. (198 lb. per sq. in.) on the abutments.

"The limestone masonry in the towers of the Niagara Suspension Bridge failed under 36 tons per sq. ft., and were taken down,—however, the masonry was not well executed.

"At the South Street Bridge, Philadelphia, the pressure on the limestone rubble masonry in the pneumatic piles is 15.7 tons per sq. ft. (220 lb. per sq. in.) at the bottom and 12 tons per sq. ft. at the top. The maximum pressure on the rubble masonry (laid in cement mortar) of some of the large masonry dams is from 11 to 14 tons per sq. ft. (154 to 195 lb. per sq. in.). The Quaker Bridge dam was designed for a maximum pressure of 16⅔ tons per sq. ft. (230 lb. per sq. in.)on massive rubble masonry in best hydraulic cement mortar.

"In the light of the preceding examples, it may be assumed that the safe load for the different classes of masonry is about as follows, *provided each is the best of its class:*

	Net tons per square foot	Pounds per square inch
Rubble....................................	10 to 15	140 to 200
Squared stone....................................	15 to 20	200 to 280
Limestone ashlar....................................	20 to 25	280 to 350
Granite ashlar....................................	25 to 30	350 to 400
Concrete....................................	30 to 40	400 to 550

Allowable Pressures under Building Codes.—Building codes of various cities in the United States vary widely in regard to pressures allowed on stone masonry. A tabulation of limits and averages permitted by the codes of six cities is given on p. 1530:

Kind of stone	Pressures (tons per sq. ft.)		
	High	Low	Average
Granite—cut	72	43	57.5
Marble and limestone—cut	50	20	38.5
Hard sandstone—cut	30	12	21.0

Mr. Thomas Nolan, in Kidder's Pocket Book gives the following as allowable loads for different kinds of stonework, and states that "in determining the safe compressive resistance of masonry from tests on the ultimate compressive strength of the same kind, a factor of safety of at least 10 should be allowed for piers and 20 for arches."

	Tons per square foot
Rubble walls, irregular stones	3
Rubble walls, coursed, soft stone	2½
Rubble walls, coursed, hard stone	5 to 16
Dimension-stone, squared, in cement mortar:	
Sandstone and limestone	10 to 20
Granite	20 to 40
Dressed stone, with ⅜-in. dressed joints, in Portland-cement mortar:	
Granite	60
Marble or limestone, best	40
Sandstone	30

APPENDIX J

STANDARD SPECIFICATIONS FOR CONCRETE AND REINFORCED CONCRETE*

CONTENTS

CHAPTER I

General Instructions

1. These specifications cover the general conditions affecting the use of concrete and reinforced concrete. To use them in connection with the contract it will be necessary for the Engineer to:

(a) Provide the detail specifications covering the work in particular in which the concrete and reinforced concrete are to be used;

(b) Section 7, Table 1, insert percentages required;

(c) Section 10, fill in the blank indicating percentage of mortar strength required of fine aggregate as compared with standard Ottawa sand;

(d) Section 11, Table 2, insert sieve sizes and percentages required;

(e) Section 21, strike out one of the titles of the specifications for reinforcement bars; if billet steel bars are to be used, indicate whether structural, intermediate, or hard grade;

(f) Section 24, strike out one of the titles of the specifications for structural steel shapes;

(g) Section 28, strike out "volume" or "weight;"

(h) Section 29, if no tests of concrete are to be made, strike out the last paragraph in accordance with the footnote. In Table 4, insert the concrete strengths which are assumed as the basis for design of the different portions of the work;

(i) Section 30, Table 5, insert the slumps required;

(j) Section 51, strike out the method or methods for depositing concrete under water which are not applicable to the work;

(k) Chapter X, strike out sections on surface finish which do not apply;

(l) Section 95, strike out one of the two sections on terrazzo finish.

CHAPTER II

Definitions

2. The following definitions give the meaning of certain terms as used in these specifications:

Acid Proofing.—Treatment of a concrete surface in order to provide resistance to the action of acids.

Aggregate.—Inert material which is mixed with Portland cement and water to produce concrete; in general, aggregate consists of sand, pebbles, gravel, crushed stone, or similar materials. (See *Fine Aggregate; Coarse Aggregate.*)

Anchorage.—The embedment in concrete of a portion of a reinforcement bar, either straight or with hooks, designed to prevent pulling out or slipping of the bar when subjected to stress. (The anchorage of tension reinforcement in beams includes only the embedded length beyond a point of contraflexure or of zero moment.)

Approved.—Meeting the approval of, or specifically authorized by, the Engineer.

Buttressed Retaining Wall.—A retaining wall with brackets or buttresses on the side opposite the pressure face uniting the upright section with the toe of the base.

Cantilever Retaining Wall.—A reinforced concrete wall having an upright section and a base each of which resists by cantilever action the pressure to which it is subjected.

Cellular Retaining Wall.—A retaining wall with a base, longitudinal upright sections, and a series of transverse walls, dividing the space between the longitudinal sections into cells which are filled with earth or other suitable material.

Coarse Aggregate.—Aggregate, subject to specified tolerances, retained on a No. 4 sieve and of a maximum size generally not larger than 3 in. (See *Aggregate; Fine Aggregate.*)

Column.—An upright compression member the length of which exceeds three times its least lateral dimension.

Column Capital.—An enlargement of the upper end of a reinforced concrete column designed and built to act as a unit with the column and flat slab.

Column Strip.—A portion of a panel of a flat slab which has a uniform width equal to one-fourth of the panel length perpendicular to the direction of the strip, and the outer edge of which lies on the edge of the panel. (See *Middle Strip;* also, Fig. 15.)

Composite Column.—A circumferentially reinforced concrete column with a core of structural steel or cast iron which is designed to carry a portion of the load.

Concrete.—A mixture of Portland cement, fine aggregate, coarse aggregate, and water. (See *Mortar.*)

Consistency.—A general term used to designate the relative plasticity of freshly mixed concrete or mortar.

Counterforted Retaining Wall.—A reinforced concrete wall with brackets or counterforts on the pressure face uniting the upright section to the heel of the base.

Crusher-Run Stone.—Unscreened crushed stone. (See *Stone Screenings.*)

Cyclopean Concrete.—Concrete in which stones weighing more than 100 lb. are individually embedded.

Dead Load.—Weight of the permanent parts of the structure.

Deformed Bar.—Reinforcement bar with shoulders, lugs, or projections formed integrally with the bar during rolling.

Diagonal Direction.—A direction parallel or approximately parallel to the diagonal of the panel of a flat slab.

Dropped Panel.—The structural portion of a flat slab which is thickened throughout an area surrounding the column capital.

Effective Area of Concrete.—The area of a section of the concrete which lies between the tension reinforcement and the compression surface in a beam or slab.

Effective Area of Reinforcement.—The area obtained by multiplying the right cross-sectional area of the metal reinforcement by the cosine of the angle between its direction and that for which the effectiveness of the reinforcement is to be determined.

Engineer.—The engineer in responsible charge of the work.

Fine Aggregate.—Aggregate, subject to specified tolerances, passing through a No. 4 sieve. (See *Aggregate; Coarse Aggregate.*)

Flat Slab.—A concrete slab having reinforcement bars extending in two or more directions without beams or girders to carry the load to supporting members.

Footing.—A structural unit used to distribute wall or column loads to the foundation materials.

Gravel.—Rounded particles larger than sand resulting from the natural disintegration of rocks. (See *Sand.*)

Laitance.—Extremely fine material of little or no hardness which may collect on the surface of freshly deposited concrete or mortar, resulting from the use of excess mixing water, and usually recognized by its relatively light color.

Live Load.—Loads and forces other than the dead load.

Middle Strip.—The portion of a panel of a flat slab which extends in a direction parallel to a side of the panel, the width of which is one-half the panel length at right angles to the direction of the strip and the center line of which lies on the center line of the panel. (See *Column Strip*; also, Fig. 15.)

Mortar.—A mixture of Portland cement, fine aggregate, and water. (See *Concrete.*)

Negative Reinforcement.—Reinforcement so placed as to take tensile stress due to negative bending moment.

Oil-Proofing.—Treatment of a concrete surface for the purpose of preventing the penetration of, and resisting the action of, oils.

Panel Length.—The distance in either rectangular direction between centers of two columns of a panel.

Pedestal.—An upright compression member the height of which does not exceed three times its least lateral dimension.

Pedestal Footing.—A column footing projecting less than one-half its depth from the faces of the column on all sides and having a depth not more than three times its least width.

Plain Concrete.—Concrete without metal reinforcement.

Portland Cement.—The product obtained by finely pulverizing clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination except water and calcined or uncalcined gypsum.

Positive Reinforcement.—Reinforcement so placed as to take tensile stress due to positive bending moment.

Principal Design Section.—The vertical sections in a flat slab on which the moments in the rectangular directions are critical. (See Section 113.)

Ratio of Reinforcement.—The ratio of the effective area of the reinforcement cut by a section of a beam or slab to the effective area of the concrete cut by that section.

Rectangular Direction.—A direction parallel to a side of the panel of a flat slab.

Reinforced Concrete.—Concrete in which metal is embedded in such a manner that the two materials act together in resisting forces.

Rubble Aggregate.—Stone or gravel larger than 3 in. in diameter and weighing not more than 100 lb.

Rubble Concrete.—Concrete in which pieces of rubble aggregate are individually embedded. (See *Rubble Aggregate.*)

Sand.—Small grains resulting from the natural disintegration of rocks. (See *Gravel.*)

Screen.—A metal plate with closely spaced circular perforations. (See *Sieve.*)

Sieve.—Woven wire cloth with square openings. (See *Screen.*)

Slump.—The shortening of a standard test mass of freshly mixed concrete, used as a measure of workability in accordance with the standard method.

Standard Sand.—Natural sand from Ottawa, Ill., screened to pass a No. 20 sieve and retained on a No. 30 sieve, used as the fine aggregate in standard strength tests of Portland cement.

Stone Screenings.—Crushed stone, subject to specified tolerances, passing through a No. 4 sieve. (See *Crusher-Run Stone.*)

Strut.—A compression member other than a column or pedestal.

Tremie.—A water-tight pipe of suitable dimensions, generally used in a vertical position, for depositing concrete under water.

Wall-Beam.—A reinforced concrete beam which extends from column to column along the outer edge of a wall panel.

CHAPTER III

Quality of Concrete

3. *Strength.*—The design of the various portions of the structure is based on the assumption that the concrete will develop the compressive strengths at 28 days, which, for purposes of design only, are given in Section 29, Table 4.

4. *Tests of Field Specimens.*—The making, curing, and testing of field concrete test specimens shall be carried out in accordance with the "Standard Methods of Making and Storing Specimens of Concrete in the Field" (Serial Designation: C31–21) of the American Society for Testing Materials.

CHAPTER IV

Materials*

A. Portland Cement

5. *Portland Cement.*—Portland cement shall conform to the "Standard Specifications and Tests for Portland Cement"† (Serial Designation: C9–21) of the American Society for Testing Materials, and subsequent revisions thereof.

B. Fine Aggregate

6. *General Requirements.*—Fine aggregate shall consist of sand, or other approved inert materials with similar cha[illegible] the of, ha[illegible] cle[illegible] rd, [illegible]ed grains and free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam, or other deleterious substances.

7. *Grading.*—Fine aggregate shall range in size from fine to coarse within the limits indicated in Table 1.

Table 1.—Grading of Fine Aggregate

Item		Percentage by weight
Passing through No. 4 sieve, not less than		(*a*)*
Passing through No. 50 sieve	not more than	(*b*)*
	not less than	(*c*)*
Weight removed by decantation, not more than		(*d*)*

* The grading requirements will vary with the type of work and characteristics of materials available in any given locality. Wherever practicable the following values should be inserted: (*a*) = 85 %; (*b*) = 30 %; (*c*) = 10 %; (*d*) = 3 %.

8. *Sieve Analysis.*—The sieves and method of making sieve analysis shall conform to the "Standard Method of Test for Sieve Analysis of Aggregates for Concrete" (Serial Designation: C41–24) of the American Society for Testing Materials.

9. *Decantation Test.*—The decantation test shall be made in accordance with the "Tentative Method of Decantation Test for Sand and Other Fine Aggregates" (Serial Designation: D136–22T) of the American Society for Testing Materials.

10. *Mortar Strength Test.*—Fine aggregate shall be of such quality that mortar briquettes, cylinders, or prisms, consisting of one part by weight of Portland cement and three parts by weight of fine aggre-

* These specifications cover the usual requirements for aggregate. Where concrete having special properties is essential the specifications should make clear the characteristics of the aggregate to be used.

† These specifications are also the standard of the following: United States Government, American Railway Engineering Association, American Concrete Institute, Portland Cement Association, and have been approved by the American Engineering Standards Committee as an American Standard.

gate,* mixed and tested in accordance with the methods described in the "Standard Specifications and Tests for Portland Cement" (Serial Designation: C9–21) of the American Society for Testing Materials, will show a tensile or compressive strength at ages of 7 and 28 days not less than . . . † per cent of that of 1:3 standard Ottawa sand mortar of the same plasticity made with the same cement. Concrete tests shall be made in accordance with the "Tentative Methods of Making Compression Tests of Concrete" (Serial Designation: C39–21T) of the American Society for Testing Materials.

11. *Organic Impurities in Sand.*—Sand when tested in accordance with the "Standard Method of Test for Organic Impurities in Sands for Concrete" (Serial Designation: C40–22) of the American Society for Testing Materials shall show a color not darker than the standard color unless it complies with Section 10.

12. *Permissible Variations.*—Fine aggregate which does not conform to the above requirements for grading, mortar strength, or color, may be used only when approved by the Engineer and then in such proportions as he may require.

C. Coarse Aggregate

13. *General Requirements.*—Coarse aggregates shall consist of crushed stone, gravel, or other approved inert materials with similar characteristics or combinations thereof, having clean, hard, strong, durable, uncoated particles free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali, organic, or other deleterious matter.

14. *Grading.*—Coarse aggregate‡ shall range in size from fine to coarse within the limits given in Table 2.

Table 2.—Size and Grading of Coarse Aggregate

Passing	Percentage by weight
. . . . * in. sieve (maximum size)	Not less than 95
. . . . * in. sieve (intermediate size)	Not less than. . . . * Not less than. . . . *
No. 4 sieve	Not more than 10
No. 8 sieve	Not more than 5

* The Engineer must insert in these blanks the sizes and percentages required with regard to materials available. The following table indicates desirable gradings for coarse aggregates of certain nominal maximum sizes:

Nominal maximum size of aggregate in inches	Percentage by weight passing through standard sieves with square openings						Percentage passing not more than:	
	3 in.	2 in.	1½ in.	1 in.	¾ in.	½ in.	No. 4 sieve	No. 8 sieve
3	95	..	40–75	.....	.....	..	10	5
2	..	95	.....	40–75	.....	..	10	5
1½	..	..	95	.....	40–75	..	10	5
1	..	..	.....	95	.....	..	10	5
¾	..	..	.....	.....	95	..	10	5
½	..	..	.....	.....	.....	95	10	5

15. *Sieve Sizes.*—The test for size and grading of aggregate shall be made in accordance with the "Standard Method of Test for Sieve Analysis of Aggregates for Concrete" (Serial Designation: C14–24) of the American Society for Testing Materials.

16. *Permissible Variations.*—Coarse aggregate§ which does not conform to the above requirements, may be used only when approved by the Engineer and then in such proportions as he may require.

* In testing aggregate, care should be exercised to avoid the removal of any coating on the grains which may affect the strength. Sand should not be dried before being made into mortar, but should contain its natural moisture. The quantity of water contained may be determined on a separate sample and the weight of the sand used in the test corrected accordingly.

† This percentage must be inserted by the Engineer; it should preferably be 100.

‡ On work of considerable magnitude where several suitable coarse aggregates are available, an investigation of the relative economy of each is advisable.

§ Requirements for the quality of coarse aggregate for special purposes should be inserted.

D. Rubble and Cyclopean Aggregate

17. *Rubble Aggregate.*—Rubble aggregate shall consist of clean, hard, durable stone or gravel larger than 3 in. and weighing not more than 100 lb.

18. *Cyclopean Aggregate.*—Cyclopean aggregate shall consist of clean, hard, durable stone weighing more than 100 lb.

E. Storage of Aggregate

19. *Storage of Aggregate.*—Aggregate shall be so stored as to avoid the inclusion of foreign materials. Frozen aggregate or aggregate containing lumps of frozen material shall be thawed before using.

F. Water

20. *General Requirements.* – Water for concrete shall be clean and free from injurious amounts of oil, acid, alkali, organic matters, or other deleterious substance.

G. Metal Reinforcement

21. *Quality.* - Metal reinforcement shall meet the requirements of the :

"Standard Specifications* for Billet-Steel Concrete Reinforcement Bars" . . . *Grade (Serial Designation: A15 14) of the American Society for Testing Materials.

"Standard Specifications* for Rail-Steel Concrete Reinforcement Bars" (Serial Designation: A16-14) of the American Society for Testing Materials, except that the provision for machining deformed bars before testing shall be eliminated.

22. *Standard Sizes of Bars.*—Reinforcement bars shall conform to the areas and equivalent sizes shown in Table 3.

Table 3.—Sizes and Areas of Reinforcement Bars§

Size of bar, in inches	Area, in square inches	
	Round bar	Square bar
3/8	0.110	.....
1/2	0.196	0.250
5/8	0.306	.....
3/4	0.441	.....
7/8	0.601	.....
1	0.785	1.000
1 1/8	.....	1.265
1 1/4	....	1.562

§ The Joint Conference of Representatives of Manufacturers, Distributors, and Users of Concrete Reinforcement Bars held in the Department of Commerce, Washington, D. C., September 9, 1924. unanimously adopted the areas and sizes of reinforcement bars in Table 3, with the addition of the 1/4 in., round bar, 0.049 sq. in.; to become effective as applying to new production, January 1, 1925; every effort to be made to clear current orders and existing stocks of eliminated areas before March 1, 1925.

23. *Deformed Bars.*—An approved deformed bar shall be one that will develop a bond at least 25 % greater than that of a plain round bar of equivalent cross-sectional area.† The areas of deformed bars shall be determined by the minimum cross-section thereof.

24. *Structural Shapes.*—Structural steel shapes used for reinforcement shall conform to the requirements of the:

"Standard Specifications‡ for Structural Steel Bridges" (Serial Designation: A7–24) of the American Society for Testing Materials.

"Standard Specifications‡ for Structural Steel for Buildings" (Serial Designation: A9-24) of the American Society for Testing Materials.

25. *Wire.*—Wire for concrete reinforcement shall conform to the requirements of the "Tentative Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement" (Serial Designation: A82–21T) of the American Society for Testing Materials.

* The Engineer must strike out one of these titles. The Committee recommends, as preferred material for reinforcement, that meeting the requirements of the "Standard Specifications for Billet-Steel Concrete Reinforcement Bars" of intermediate grade, made by the open-hearth process, except that the provisions for machining the test specimens shall be eliminated.

† The Committee has under consideration a specification for deformed bars, but is not prepared at this time to make more definite recommendations.

‡ The Engineer must strike out one of these titles.

26. *Cast Iron.*—Cast iron used in composite columns shall conform to the requirements of the "Standard Specifications for Cast-Iron Pipe and Special Castings" (Serial Designation: A44–04) of the American Society for Testing Materials.

CHAPTER V

Proportioning and Mixing Concrete

A. Proportioning

27. *Unit of Measure.*—The unit of measure shall be the cubic foot. Ninety-four (94) pounds of Portland cement (one bag or ¼ bbl.) shall be considered as one (1) cubic foot.

28. *Measurement of Aggregates.*—The method of measurement shall be such as to secure th specified proportions in each batch. The aggregate shall be measured separately by volume[1] weight.[1]

In volume measurement the fine aggregate and the coarse aggregate shall be measured loose, as thrown into the measuring device, and struck off.[2] The water shall be so measured as to insure the desired quantity in successive batches.

29. *Proportions.*—Concrete shall be mixed in the proportions indicated in Table 4.

Variations in the grading of the aggregates, on which the proportions were based, may be made upon the approval of the Engineer and in such proportions as he may direct (Sections 3 and 14), but no claim shall be made for extra compensation therefor.

Table 4.—Proportions for Concrete*

Part of structure	Proportions by volume			Concrete strength† assumed as basis for design, in pounds per square inch at 28 days
	Cement	Fine aggregate	Coarse aggregate	
Footings	....	......	....	‡
Beams, girders, slabs	.....	.....	....	‡
Columns	.....	.....	......	‡
....	.....	.....	....	‡
....	.....	.....	.....	‡
....	.....	.....	..	‡

* The Engineer should determine, by tests of the available aggregate in advance of use, the proportions necessary to produce concrete of the required strength. Where this is impracticable, Appendix XVI may be used as a guide. Appendix XVI is based on volumes of dry aggregate compacted by rodding in the measure, as specified in "Standard Method of Test for Unit Weight of Aggregate for Concrete," see Appendix XV. Corrections should be made in the quantities in Appendix XVI to take account of the bulking effect of moisture in the fine aggregate. The bulking (swelling) of fine aggregate due to contained moisture and the method of placing it in the measure, may result in a reduction of 25 % in the actual quantity of fine aggregate, as compared with that obtained by dry measurement by the standard method.

† The measure of the quality of concrete is its workability, as determined by the slump test, or other approved test, and its compressive strength of 28 days, using the materials in the proportions specified.

‡ Concrete strengths to be used as basis for design to be filled in by the Engineer.

The Engineer shall have the right to make any changes in proportions (aterials that may be necessary or desirable, and proper adjustment of compensation will be mad accordance with the provisions of the contract.

In general, the quantity of water used shall be the minimum necessary to produce concrete of a workability specified in Table 5.

Frequent tests[3] shall be made throughout the work, as directed by the Engineer, to determine whether the concrete produced by the proportions given in Table 4 is of the quality specified. These tests shall be made in accordance with Section 4 and at the expense of the owner. The Contractor shall provide such facilities as may be practicable for carrying out the tests, and shall cooperate in every way to the end that concrete of the desired quality shall be obtained.

[1] The Engineer must strike out one of these terms.

[2] The volume of fine aggregate is affected by the method of measurement and by the moisture content; corrections should be made, when necessary, to maintain the required proportions; see, also, footnote to Table 4.

[3] If no tests are to be made on concrete from available materials, or on the concrete mixed during the work, this paragraph must be omitted.

B. Consistency of Concrete

30. *Consistency.*—The quantity of water used shall be the minimum necessary to produce concrete of a workability required by the Engineer.‡ The consistency of the concrete shall be measured by the slump test as described in "Tentative Method of Test of Consistency of Portland-Cement Concrete for Pavements or for Pavement Base" (Serial Designation: D138–22T) of the American Society for Testing Materials. The slump for the different types of concrete shall not be greater than that indicated in Table 5, unless authorized by the Engineer.

The consistency shall be checked from time to time during the progress of the work.

Table 5.—Workability of Concrete and Mortar

Types of concrete and mortar	Maximum slump, in inches
Mass concrete	*
Reinforced concrete:	
(a) Thin vertical sections and columns	*
(b) Heavy sections	*
(c) Thin confined horizontal sections	*
Roads and pavement:	
(a) Hand-finished	*
(b) Machine-finished	*
Mortar for floor finish	*

* The Engineer must insert the maximum slumps permitted. The slump-test requirement is intended to insure concrete mixed with the minimum quantity of water required to produce a plastic mixture. The following table indicates the maximum slump desirable for the various types of concrete, based on average aggregates and proportions:

Types of concrete and mortar	Maximum slump, in inches
Mass concrete	3
Reinforced concrete:	
(a) Thin vertical sections and columns	6
(b) Heavy sections	3
(c) Thin confined horizontal sections	8
Roads and pavements:	
(a) Hand-finished	3
(b) Machine-finished	1
Mortar for floor finish	2

C. Mixing

31. *Machine-Mixing.*—The mixing of concrete, unless otherwise authorized by the Engineer, shall be done in a batch mixer of approved type which will insure a uniform distribution of the materials throughout the mass, so that the mixture is uniform in color and homogeneous. The mixer shall be equipped with suitable charging hopper, water storage, and a water-measuring device controlled from a case which can be kept locked and so constructed that the water can be discharged only while the mixer is being charged. It shall also be equipped with an attachment for automatically locking the discharge lever until the batch has been mixed the required time after all materials are in the mixer. The entire contents of the drum shall be discharged before recharging. The mixer shall be cleaned at frequent intervals while in use. The volume of the mixed material per batch shall not exceed the manufacturer's rated capacity of the mixer.

32. *Time of Mixing.*—The mixing of each batch shall continue not less than 1 min. after all the materials are in the mixer, during which time the mixer shall rotate at a peripheral speed of about 200 ft. per min.

33. *Hand-Mixing.*—When hand-mixing is authorised by the Engineer it shall be done on a water-tight platform. The cement and fine aggregate shall first be mixed dry until the whole is of a uniform color. The water and coarse aggregate shall then be added and the entire mass turned at least three (3) times, or until a homogenerous mixture of the required consistency is obtained.

34. *Retempering.*—The retempering of concreteor mortar which has partly hardened, that is, remixing with or without additional cement, aggregate, or water, will not be permitted.

‡ Attention is called to the fact that increased workability may be obtained by decreasing the quantity of coarse aggregate in the batch, without increasing the quantity of mixing water.

CHAPTER VI

DEPOSITING CONCRETE

A. DEPOSITING IN AIR

35. *General.*—Before beginning a run of concrete, hardened concrete and foreign materials shall be removed from the inner surfaces of the mixing and conveying equipment.

36. *Approval.*—Before depositing concrete, débris shall be removed from the space to be occupied by concrete; forms shall be thoroughly wetted (except in freezing weather), or oiled. Reinforcement shall be thoroughly secured in position and approved by the Engineer.

37. *Handling.*—Concrete shall be handled from the mixer to the place of final deposit as rapidly as practicable by methods which prevent the separation or loss of the ingredients. It shall be deposited in the forms as nearly as practicable in its final position to avoid rehandling. It shall be so deposited as to maintain until the completion of the unit, a plastic surface approximately horizontal. Forms for walls or other thin sections of considerable height shall be provided with openings, or other devices, that will permit the concrete to be placed in a manner that will avoid accumulations of hardened concrete on the forms or metal reinforcement. Under no circumstances shall concrete that has partly hardened be deposited in the work.

38. *Chuting.*—When concrete is conveyed by chuting, the plant shall be of such size and design as to insure a practically continuous flow in the chute. The angle of the chute with the horizontal shall be such as to allow the concrete to flow without separation of the ingredients.* The delivery end of the chute shall be as close as possible to the point of deposit. When the operation is intermittent, the spout shall discharge into a hopper. The chute shall be thoroughly flushed with water before and after each run; the water used for this purpose shall be discharged outside the forms.

39. *Compacting.*—Concrete, during and immediately after depositing, shall be thoroughly compacted by means of suitable tools. For thin walls or inaccessible portions of the forms, where rodding or forking is impracticable, the concrete shall be assisted into place by tapping or hammering the forms opposite the freshly deposited concrete. The concrete shall be thoroughly worked around the reinforcement, and around embedded fixtures, and into the corners of the forms.

40. *Removal of Water.*—Water shall be removed from excavations before concrete is deposited, unless otherwise directed by the Engineer. Any flow of water into the excavation shall be diverted through proper side-drains to a sump, or be removed by other approved methods which will avoid washing the freshly deposited concrete. Water vent pipes and drains shall be filled by grouting, or otherwise, after the concrete has thoroughly hardened.

41. *Protection.*—Exposed surfaces of concrete shall be protected from premature drying for a period of at least seven (7) days after being deposited.

42. *Temperature of Concrete.*—Concrete when deposited shall have a temperature of not less than 40° Fahr., nor more than 120° Fahr. In freezing weather suitable means shall be provided for maintaining the concrete at a temperature of at least 50° Fahr. for not less than 72 hours after placing, or until the concrete has thoroughly hardened. The methods of heating the materials and protecting the concrete shall be approved by the Engineer. Salt, chemicals, or other foreign materials shall not be mixed with the concrete for the purpose of preventing freezing, unless approved by the Engineer.

43. *Depositing Continuously.*—Concrete shall be deposited continuously and as rapidly as practicable until the unit of operation, approved by the Engineer, is completed. Construction joints at points not provided for in the plans shall be made in accordance with the provisions in Section 69.

44. *Bonding.*—Before depositing new concrete on or against concrete which has set, the forms shall be re-tightened, the surface of the set concrete shall be roughened as required by the Engineer, thoroughly cleaned of foreign matter and laitance, and saturated with water. The new concrete placed in contact with hardened or partly hardened concrete, shall contain an excess of mortar to insure bond. To insure this excess mortar at the juncture of the hardened and the newly deposited concrete the cleaned and saturated surfaces of the hardened concrete, including vertical and inclined surfaces, shall first be slushed with a coating of neat cement grout against which the new concrete shall be placed before the grout has attained its initial set.

B. RUBBLE AND CYCLOPEAN CONCRETE

45. *Rubble Concrete.*—Rubble aggregate shall be thoroughly embedded in the concrete. The individual stones shall not be closer to any surface or adjacent stone than the maximum size of the coarse aggregate plus 1 in. Each successive layer of concrete shall be keyed in accordance with the provision in Section 69.

46. *Cyclopean Concrete.*—Cyclopean aggregate shall be thoroughly embedded in the concrete; no stone shall be closer to a finished surface than 1 ft., nor closer than 6 in. to any adjacent stone. Stratified stone shall be laid on its natural bed.

* An angle of 27°, or one vertical to two horizontal, is the minimum slope which is considered permissible. Chuting through a vertical pipe is satisfactory when the lower end of the pipe is maintained as nearly as practicable, to the surface of deposit and the pipe full.

C. Depositing under Water*

47. *General.*—The methods, equipment, and materials to be used shall be submitted to and be approved by the Engineer before the work is started. Concrete shall be deposited by a method that will prevent the washing of the cement from the mixture, minimize the formation of laitance, and avoid flow of water until the concrete has fully hardened. Concrete shall be placed so as to minimize segregation of materials. Concrete shall not be placed in water having a temperature below 35° Fahr.

48. *Proportions.*—Concrete to be deposited under water shall contain 1¾ bbl. (7 bags) or more of Portland cement per cubic yard of concrete in place.

49. *Coffer-Dams.*—Coffer-dams shall be sufficiently tight to prevent flow of water through the space in which the concrete is to be deposited. Pumping will not be permitted while concrete is being deposited, nor until it has fully hardened.

50. *Depositing Continuously.*—Concrete shall be deposited continuously, keeping the top surface as nearly level as possible, until it is brought above the water, or to the required height. The work shall be carried on with sufficient rapidity to prevent the formation of layers.

51. *Method.*—The following method† shall be used for depositing concrete under water:

Tremie.—The tremie shall be water-tight and sufficiently large to permit a free flow of concrete. It shall be kept filled‡ at all times during depositing. The concrete shall be discharged and spread by raising the tremie in such manner as to maintain as nearly as practicable a uniform flow and avoid dropping the concrete through water. If the charge is lost during depositing the tremie shall be withdrawn and refilled.

Drop-Bottom Bucket.—The bucket shall be of a type that cannot be dumped until it rests on the surface upon which the concrete is to be deposited. The bottom doors when tripped shall open freely downward and outward. The top of the bucket shall be open. The bucket shall be completely filled, and slowly lowered to avoid back-wash. When discharged, t e bucket shall be withdrawn slowly until well above the concrete.

Bags.—Bags of jute or other coarse cloth shall be filled about two-thirds (⅔) full of concrete and carefully placed by hand in a header-and-stretcher system so that the whole mass is interlocked.

52. *Laitance.*—Great care shall be exercised to disturb the concrete as little as possible when it is being deposited in order to avoid the formation of laitance. On completing a section of concrete, the laitance shall be entirely removed before work is resumed.

CHAPTER VII

Forms

53. *General.*—Forms shall conform to the shape, lines, and dimensions of the concrete as called for on the plans. Lumber used in forms for exposed surfaces shall be dressed to a uniform thickness, and shall be free from loose knots or other defects. Joints in forms shall be horizontal or vertical. For unexposed surfaces and rough work undressed lumber may be used. Lumber once used in forms shall have nails withdrawn and surfaces to be in contact with concrete thoroughly cleaned before being used again.

54. *Design.*—Forms shall be substantial and sufficiently right to prevent leakage of mortar; they shall be properly braced or tied together so as to maintain position and shape. If adequate foundation for shores cannot be secured, trussed supports shall be provided.

55. *Workmanship.*—Bolts and rods shall preferably be used for internal ties; they shall be so arranged that when the forms are removed no metal shall be within 1 in. of any surface. Wire ties will be permitted only on light and unimportant work; they shall not be used through surfaces where discoloration would be objectionable. Shores supporting successive stories shall be placed directly over those below, or so designed that the load will be transmitted directly to them. Forms shall be set to line and grade and so constructed and fastened as to produce true lines. Special care shall be used to prevent bulging.

56. *Mouldings.*—Unless otherwise specified suitable mouldings or bevels shall be placed in the angles of forms to round or bevel the edges of the concrete.

57. *Oiling.*—The inside of forms shall be coated with non-staining mineral oil or other approved material, or thoroughly wetted (except in freezing weather). Where oil is used, it shall be applied before the reinforcement is placed.

* Concrete should not be deposited under water if practicable to deposit in air. There is always uncertainty as to results obtained from placing concrete under water. Where conditions permit, the additional expense and delay of avoiding this method will be warranted. It is especially important that the aggregate be free from loam and other material which may cause laitance. Washed aggregates are preferable. Coarse aggregate consisting of washed gravel of a somewhat smaller size than that used in open-air concrete work will give best results. Concrete should never be deposited under water without experienced supervision. Many failures, especially of structures in sea water, can be traced directly to ignorance of proper methods or lack of expert supervision.

† The Engineer must strike out the method or methods not applicable to the work.

‡ The tremie may be filled by one of the following methods: (1) Place the lower end in a box partly filled with concrete, so as to seal the bottom, then lower into position; (2) plug the tremie with cloth sacks or other material, which will be forced d..wn as the pipe is filled with concrete; (3) plug the end of the tremie with cloth sacks filled with concrete.

58. *Inspection.*—Temporary openings shall be provided at the base of column and wall forms and at other points where necessary to facilitate cleaning and inspection immediately before depositing concrete.

59. *Removal.*—Forms shall not be disturbed until the concrete has adequately hardened.* Shoring shall not be removed until the member has acquired sufficient strength to support safely its weight and the load on it. Members subject to additional loads during construction shall be adequately shored to support both the member and construction loads in such a manner as will protect the member from damage by the loads; this shoring shall not be removed until the member has acquired sufficient strength to support safely its weight and the load on it.

CHAPTER VIII

Details of Construction

A. Metal Reinforcement

60. *Cleaning.*—Metal reinforcement, before being positioned, shall be thoroughly cleaned of mill and rust scale and of coatings that will destroy or reduce the bond. Reinforcement appreciably reduced in section shall be rejected. Where there is delay in depositing concrete, reinforcement shall be reinspected and, when necessary, cleaned.

61. *Bending.*—Reinforcement shall be carefully formed to the dimensions indicated on the plans, or as provided in Section 140. Cold bends shall be made around a pin having a diameter of four (4) or more times the least dimension of the reinforcement bars for steel of structural grade and eight (8) or more times that for steel of intermediate or hard grade.

62. *Straightening.*—Metal reinforcement shall not be bent or straightened in a manner that will injure the material. Bars with kinks or bends not shown on the plans shall not be used. Heating of reinforcement will be permitted only when the entire operation is approved by the Engineer.

63. *Placing.*—Metal reinforcement shall be accurately positioned, and secured against displacement by using annealed iron wire of not less than No. 18 gauge, or suitable clips at intersections, and shall be supported by concrete or metal chairs or spacers, or metal hangers. The minimum clear distance between parallel bars shall be one and one-half (1½) times the diameter of round bars, or one and one-half (1½) times the diagonal of square bars; if the ends of bars are anchored as specified in Section 140, the clear spacing may be made equal to the diameter of round bars, or to the diagonal of square bars, but in no case shall the spacing between bars be less than 1 in., nor less than one and one-quarter (1¼) times the maximum size of the coarse aggregate. Bars parallel to the face of any member shall be embedded a clear distance of not less than one (1) diameter from the face.

64. *Splicing.*—In slabs, beams, and girders, splices of reinforcement shall not be made at points of maximum stress without the approval of the Engineer. Splices, where permitted, shall provide sufficient lap to transfer the stress between bars by bond and shear. In such splices the bars shall be placed at the minimum distance specified in Section 63; adjacent bars shall not be spliced at the same point.

Splices in columns, piers, and struts shall provide sufficient lap to transfer the stress by bond.

65. *Offsets in Reinforcement of Compressing Members.*—Where changes in the cross-section of a compression member occur, the longitudinal reinforcement bars shall be sloped for the full length of the member, or offset in a region where lateral support is afforded. Where offset, the slope of the inclined portion from the axis of the member shall not be more than 1 in 6.

66. *Future Bonding.*—Exposed reinforcement bars intended for bonding with future extensions shall be protected from corrosion.

B. Protective Concrete Covering

67. *Moisture Protection.*—Metal reinforcement in wall footings and column footings shall have a minimum covering of 3 in. of concrete. At surfaces of concrete exposed to the weather, metal reinforcement shall be protected by not less than 2 in. of concrete.

68. *Fire Protection.*—Metal reinforcement in fire-resistive construction shall be protected by not less than 1 in. of concrete in slabs and walls, and not less than 2 in. in beams, girders, and columns, provided aggregate showing an expansion not materially greater than that of limestone or trap-rock is used; when impracticable to obtain aggregate of this grade, the protective covering shall be 1 in. thicker and shall be reinforced with metal mesh, having openings not exceeding 3 in., placed 1 in. from the finished surface.

In structures where the fire hazard is limited, the metal reinforcement shall not be placed nearer the exposed surface than ¾ in. in slabs and walls, or 1½ in. in beams, girders, and columns.

* Many conditions affect the hardening of concrete, and the proper time for the removal of the forms should be determined by the Engineer.

C. Joints

69. *General.*—Joints not indicated on the plans shall be so designed and located as least to impair the strength and appearance of the structure. To prevent laitance in horizontal joints, excess water shall be removed from the surface forming the joint after depositing the concrete. Surfaces of contact shall be cleaned and wetted before depositing is resumed, and any laitance shall be removed. Where additional resistance to horizontal shear is required, stones shall be partly embedded in such a manner as to key with the adjoining concrete; or mortices or keys shall be formed in the concrete.

70. *Columns.*—Joints in columns shall be made at the under side of the floor. Haunches and column capitals shall be considered as part of, and to act continuous with the floor. At least two (2) hours must elapse after depositing concrete in the columns or walls before depositing in beams, girders, or slabs.

71. *Floors.*—Construction joints in floors shall be located near the middle of span of slabs, beams, or girders, unless a beam intersects a girder at this point, in which case the joints in the girders shall be offset a distance equal to twice the width of the beam. Adequate provision shall be made for shear by use of inclined reinforcement.

72. *Construction Joints in Long Buildings.*—Construction joints made cross-wise of a building 100 ft. or more in length, shall have special reinforcement placed at right angles to the joint, and extending a sufficient distance on each side of the joint, to develop the strength of the reinforcement by bond. This reinforcement shall be placed near the opposite face of the member from the main tension reinforcement; the cross-sectional area of such reinforcement shall be not less than 0.5 % of the section of the members cut by the joint.

73. *Expansion Joints.*—Expansion joints shall be so detailed that the necessary movement may occur with minimum resistance at the joint. The structure adjacent to the joint shall preferably be supported on separate columns or walls. Reinforcement shall not extend across an expansion joint; the break between the two sections shall be complete.* Exposed edges of expansion joints in walls or abutments shall be rounded. Exposed expansion joints between two distinct concrete members shall be filled with an elastic joint filler of approved quality.

74. *Expansion Joints in Long Buildings.*—Buildings exceeding 200 ft. in length and of width less than about one-half (½) the length, shall be divided by means of expansion joints, located near the middle, but not more than 200 ft. apart, to minimize the destructive effects of temperature changes and shrinkage. Where there is an abrupt change in the width of a building, an expansion joint shall be provided.

75. *Sliding Joints.*—The seat of sliding joints shall be finished to a smooth plane surface and allowed to harden. Two thicknesses of building paper shall be placed on the seat before depositing superimposed concrete.†

76. *Water-Tight Construction Joints.*—Where construction joints are required to be water-tight the method of construction shall be as follows:

(*a*) Horizontal joints shall be constructed by forming a continuous keyway in the lower portion of concrete before the concrete has hardened. Before placing the superimposed concrete, the joint shall be thoroughly cleaned of laitance or other foreign material, saturated with water, and coated with neat cement grout. The superimposed concrete shall be placed in such a manner as will insure an excess of mortar over the entire surface of the joint.

(*b*) Vertical joints shall be made by a metal water-stop approved by the Engineer.

Seepage water shall be collected and drained from the forms; where required, vent pipes shall be closed after the concrete has thoroughly hardened.‡

CHAPTER IX

Water-Proofing and Protective Treatment

A. Water-Proofing

77. *General.*—Concrete required to be water-tight shall be made with strict adherence to all provisions in these specifications regarding the choice of materials, proportions, consistency, mixing, placing, protecting, and workmanship.

78. *Integral Compounds.*—Integral compounds shall not be used for water-proofing unless specifically authorized by the Engineer.

79. *Water-Tight Joints.*—See Section 76.

B. Oil-Proofing

80. *Oil-Proofing.*—Concrete containers for light mineral oils, animal oils, certain vegetable oils, and other commercial liquids shall be given an inside coating which shall be applied before the container is

* A coating of white lead and oil, asphalt paint, petrolatum, or water-proofed building paper placed over the entire surface of the hardened concrete, is commonly used for this purpose.

† Sheet zinc, lead, and bronze are also used for this purpose.

‡ To secure water-tight joints it is vitally essential that all incoming water be drained from behind the forms during the process of concreting. If the upper portion of the joint is concreted first, a metal water-stop should be provided as directed by the Engineer.

placed in service; the coating and the method of application shall be approved by the Engineer*. Floors or other surfaces exposed to heavy concentrations of such oils or liquids shall be similarly protected.

C. CONCRETE IN SEA WATER

81. *Proportions.*—Plain concrete in sea water from 2 ft. below low water to 2 ft. above high water, or from a plane below to a plane above wave action, shall contain a minimum of 1¾ bbl. (7 bags) of Portland cement per cubic yard in place. Other plain concrete in sea water or exposed directly along the sea coast shall contain a minimum of 1½ bbl. (6 bags) of Portland cement per cubic yard in place. Porous or weak aggregates shall not be used.

82. *Consistency.*—The consistency shall meet the requirements of Section 30.

83. *Depositing.*—Sea water shall not be allowed to come in contact with the concrete until it has hardened for at least four (4) days. Concrete shall be placed in such a manner as to minimize the number of horizontal or inclined seams or work planes. The placing of concrete between tides shall be a continuous operation, in accordance with the methods described in Section 43; where it is impossible to avoid seams or joints proceed as in Section 44. Concrete shall be deposited in sea water only when so directed by the Engineer, in which case it shall be placed in accordance with the methods described in Sections 47 to 52.

84. *Protection.*—Metal reinforcement shall be placed at least 3 in. from any plane or curved surface except at corners when it shall be at least 4 in. from adjacent surfaces. Metal chairs, supports or ties shall not extend to the surface of the concrete. Where unusually severe conditions of abrasion are anticipated, the face of the concrete from 2 ft. below low water to 2 ft. above high water, or from a plane below to a plane above wave action, shall be protected by creosoted timber, dense vitrified shale brick, or stone of suitable quality, as designated on the plans or as required by the Engineer.

D. CONCRETE IN ALKALI SOILS OR WATERS†

85. *Proportions.*—Concrete in alkali waters or below the ground-line of alkali soils shall contain a minimum of 1¾ bbl. (7 bags) of Portland cement per cubic yard in place.‡

86. *Consistency.*—The consistency of concrete in alkali soils or waters shall be such as to meet the requirements of Section 30.

87. *Placing.*—Concrete shall be placed in such a manner as to minimize the number of horizontal or inclined seams, or work planes.

88. *Protection.*—Metal reinforcement or other corrodible metal shall not be placed closer than 2 in to the surface of members exposed to alkali soils or waters. In foundations and in heavy structures the metal reinforcement shall not be placed closer than 3 in. from the surface.

CHAPTER X

SURFACE FINISH§

89. *General.*—The requirements in these specifications applying to forms, and to mixing, conveying, depositing, and finishing concrete, shall be followed unless modified by the plans.

The whole of a showing face between prescribed construction joints shall be cast in one continuous operation. Construction joints, when not shown on the plans, shall be made as directed by the Engineer, and shall be true to line with sharp unbroken edges.

The same brand of cement, and the same kind and size of aggregate, shall be used throughout the whole of any showing face.

For showing faces the forms shall be smooth and water-tight. If wood be used, the boards shall be planed, grooved, and tongued, evenly matched, and tightly placed. They shall be so constructed as to

* Concrete containers for mineral oils of 30° Baumé and lighter should be given a coating which will not be affected or penetrated by mineral spirits. Coatings containing ingredients which saponify or oxidize in the presence of lime shall be applied only to a surface which has previously been treated to neutralize the lime.

Concrete containers for mineral oils heavier than 30° Baumé require no coating.

Certain vegetable and animal oils and strong acids and alkaline solutions have a destructive effect on concrete and some protective treatment is required. Several vegetable oils have a disintegrating effect on concrete in cases where the surface is alternately wet and dry, yet when stored in closed concrete containers have no injurious action.

Concrete containers for commercial liquids involve certain special features in addition to the general requirements of good concrete. Containers for such liquids often have thin sections, therefore a rich mixture is necessary to obtain concrete of proper workability without sacrificing strength and impermeability; it is especially necessary to eliminate joints or seams; thorough spading is essential and should be continuous during the placing of concrete.

† Under certain circumstances concrete is attacked by alkaline waters. The term "alkali" is here used to designate the soluble salts which occur in considerable quantities in the soils and waters of certain Western States; the sulphates, chlorides, and carbonates of sodium and magnesium are the most common forms of alkali.

It is important to distinguish between the different forms of alkali which occur in Nature. Experience and tests have shown that certain forms are more injurious than others; the chlorides and carbonates produce little or no injury to concrete.

Special care must be used in placing concrete where it will be exposed to sulphate waters. An impermeable concrete made with a durable aggregate is necessary. Concrete should be permitted to harden under favorable conditions before it is exposed to injurious alkalies, and wherever practicable such concrete should be made in the form of precast units.

‡ Where the foundations of important buildings or similar structures are subject to high concentrations of alkalies, under-drainage may be used as an added precaution.

§ The Engineer should indicate on the plans the type of finish desired and must strike out the sections which do not apply.

be removable in sections by unscrewing or otherwise loosening them without hammering or prying against the face. Any offsets in the forms that may occur shall be smoothly dressed and any openings pointed flush with stiff clay or plaster of Paris in order to prevent leakage or the formation of fins.

Concrete that is to have a showing face, whether any particular finish is called for or not, shall be mixed, placed, and worked as may be necessary to secure at the face a uniform distribution of the aggregates, freedom from void spaces, and uniform texture. If the finish is required to be one that will expose the coarse aggregate, by either scrubbing, tooling, sand-blasting, or acid treatment, then after the full surface of mortar has been worked against the form, the spading tool shall be inserted in the concrete and the coarse aggregate be pressed against the form, in order to secure uniform distribution at the face and a uniform texture after the aggregate is exposed.

Face forms shall be removed as soon as practicable in order to facilitate effective repair of void spaces or broken corners, before the surface has dried. Care shall be taken to avoid roughening or injuring corners, and to keep edges sharp.

As soon as the face forms are removed any fins or other projections shall be carefully removed, and offsets leveled, and any voids or damaged places shall immediately be saturated with water and filled with a mixture of the same composition as that used in the surface, and brought even with the surface by means of a wooden spatula or float. A steel trowel shall not be used to finish the surface. The face shall be finished free from streaks, discolorations, or other imperfections. Plastering will not be permitted.

Where a surface of mortar is to be the basis of the finish the coarse aggregate shall be worked from the form with a suitable tool, so as to bring a full surface of mortar against the form, care being taken to prevent the formation of voids and air-pockets.

Whenever forms are removed from showing faces before the concrete has become hard and dry, the surface of the concrete shall be immediately wetted and kept wet for at least three (3) days.

90. *Granolithic Surfaces.*—Granolithic surfaces shall be made by placing about 1 in. of facing concrete against the face form in advance of the concrete, of such consistency and in such a manner as will insure its bonding with the concrete.

The facing concrete shall be composed of 1 part of Portland cement, 1½ parts of fine aggregate, and 2½ parts of coarse aggregate made up of pebbles, crushed granite, or other stone as called for.

If iron or wooden moulds are used to retain the facing against the forms while placing concrete, care should be taken that the mould is not permitted to remain until initial setting occurs. The moulds shall be jarred frequently and raised at short intervals to prevent formation of seams and air spaces between the surface and the concrete.

91. *Top Surfaces not Subject to Wear.*—Top surfaces not subject to wear shall be smoothed with a wood float and be kept wet for at least seven (7) days. Care shall be taken to avoid an excess of water in the concrete, and to drain or otherwise promptly remove any water that comes to the surface. Dry cement, or a dry mixture of cement and sand, shall not be sprinkled directly on the surface.

A. Wearing Surfaces

92. *One-Course Work.*—Aggregates for the wearing surface shall have a high resistance to abrasion, and shall be screened and when necessary thoroughly washed. The least quantity of mixing water that will produce a dense concrete shall be used. The mix shall not be leaner than 1 part of Portland cement and 2½ parts of aggregate. The surface shall be screened even and finished with a wood float. Excess water shall be promptly drained or otherwise removed. Over-troweling shall be avoided.

93. *Two-Course Work.*—The wearing surface in two-course work shall be placed within one-half (½) hour after the base course. Where the wearing surface is required to be applied to a hardened base course, the latter shall be prepared by roughening with a pick or other effective tool. The roughened surface shall be thoroughly saturated with water and covered with a thin layer of neat cement paste immediately before the wearing surface is placed. The wearing course shall not be thinner than 1 in.

94. *Curing.*—Concrete wearing surfaces made in accordance with Sections 92 to 93 shall be kept wet* for at least ten (10) days in the case of floors and twenty-one (21) days in the case of roads and pavements.

95†. *Terrazzo Finish.*—Terrazzo finish shall be made by mixing 1 part of cement, 2½ parts of crushed marble, or other stone or crushed pebbles, as may be called for by the plans, and sufficient water to produce a dense concrete. The concrete shall be spread on the base course and worked down to a thickness of 1 in. by patting or rolling and troweling. The marble shall all pass a ½-in. screen and be free from dust. The surface shall be kept wet for not less than ten (10) days, and after curing shall be rubbed to a plane surface with a stone or a surfacing machine. Hardened concrete to which a terrazzo finish is to be applied shall be prepared as prescribed in Section 93.

95†. *Terrazzo Finish.*—Terrazzo finish shall be made by mixing 1 part of cement, 2 parts of sand, and sufficient water to produce a plastic mortar, which shall be spread on the base course to a depth of 1 in. Crushed marble, free from dust and passing a ¼-in. screen, shall be sprinkled over the surface of the

* Prevention of premature drying during the early hardening of concrete is essential to the development of high resistance to abrasion. The surface may be covered with a layer of burlap, earth, or sand, kept wet, or it may be divided into small areas by dikes and flooded with water to a depth of 2 or 3 in.

† The Engineer must strike out one of the Sections 95, pp. 660 and 661.

fresh mortar, and pressed or rolled in. The surface shall be kept wet for not less than ten (10) days and after curing shall be rubbed to a plane surface with a stone or a surfacing machine. Hardened concrete to which a terrazzo finish is to be applied shall be prepared as prescribed in Section 93.

B. Decorative Finishes

96. ***Rubbed Finish.***—Immediately after the forms are removed, the surface shall be wetted and rubbed with a carborundum brick or other abrasive until even and smooth and of uniform appearance, without applying any cement or other coating.

97. ***Scrubbed Finish.***—The forms must be removed and the scrubbing done before the concrete has hardened.* The surface shall be scrubbed with a fiber or wire brushes using water freely, until the surface film of mortar is removed and the aggregate uniformly exposed; then rinsed with clean water. If portions of the surface have become too hard to scrub in equal relief, dilute hydrochloric acid (1 part acid to 4 parts water) may be used to facilitate the scrubbing. The remaining acid shall be thoroughly removed with clean water.

98. ***Sand-Blast Finish.***—The concrete face shall be permitted to attain an intermediate degree of hardness; it shall then be air-blasted with hard sand until the aggregate is in uniform relief.

99. ***Tooled Finish.***—The surface shall be permitted to become dry and hard, and then dressed with tools, as called for,† to a uniform texture and even face.

100. ***Sand-Floated Finish.***—The forms shall be removed before the surface has fully hardened; the surface shall be rubbed with a wooden float by a uniform circular motion, fine sand being rubbed into the surface until the resulting finish is even and uniform.

101. ***Colored Aggregate Finish.***—Colored or other special aggregate used for finish shall be exposed by scrubbing as provided in Section 97. Facing mortar, made from this special aggregate, of 1 part of cement, 1½ parts of sand, and 3 parts of pebbles or screenings, clean and free from dust, shall be placed against the face forms to a thickness of about 1 in. sufficiently in advance of the concrete to prevent the latter coming in contact with the form.

102. ***Colored Pigment Finish.***—Mineral pigment shall be thoroughly mixed dry with the cement and fine aggregate; care shall be taken to secure a uniform tint throughout.

CHAPTER XI

Design

A. General Assumptions

103. ***General Assumptions.***—The design of reinforced concrete members under these specifications shall be based on the following assumptions:

(*a*) Calculations are made with reference to working stresses and safe loads rather than with reference to ultimate strength and ultimate loads.

(*b*) A plane section before bending remains plane after bending, shearing distortions being neglected.

(*c*) The modulus of elasticity of concrete in compression is constant within the limits of working stresses and the distribution of compressive stress in beams is rectilinear.

(*d*) The moduli of elasticity of concrete in computations for the position of the neutral axis, for the resisting moment of beams, and for compression of concrete in columns, are as follows:

1. One-fifteenth ($\frac{1}{15}$) that of steel, when the compressive strength of the concrete at 28 days exceeds 1500 and does not exceed 2200 lb. per sq. in.
2. One-twelfth ($\frac{1}{12}$) that of steel, when the compressive strength of the concrete at 28 days exceeds 2200 and does not exceed 2900 lb. per sq. in.
3. One-tenth ($\frac{1}{10}$) that of steel, when the compressive strength of the concrete at 28 days is greater than 2900 lb. per sq. in.

(*e*) In calculating the moment of resistance of reinforced concrete beams and slabs the tensile resistance of the concrete is neglected.

(*f*) The bond between the concrete and the metal reinforcement remains unbroken throughout the range of working stresses. Under compression the two materials are therefore stressed in proportion of their moduli of elasticity.

(*g*) Initial stress in the reinforcement due to contraction or expansion of the concrete is neglected, except in the design of reinforced concrete columns.‡

B. Flexure of Rectangular Reinforced Concrete Beams and Slabs

104. ***Flexure Formulas.***—Computations of flexure in rectangular reinforced concrete beams and slabs shall be based on the following formulas:

(*a*) ***Reinforced for Tension Only:***

Position of neutral axis,

$$k = \sqrt{2pn + (pn)^2} - pn \qquad (1)$$

* In warm weather this will require from 6 to 24 hours, and in cold weather from 1 to 3 days.

† By axing, rough or fine pointing, or bush-hammering.

‡ Formula (43) for the permissible compressive stress in reinforced concrete columns takes into account the effect of shrinkage in the concrete on the stress in the longitudinal reinforcement. It is not required, however, that the designer consider shrinkage stresses in columns, except through the use of that formula.

Arm* of resisting couple,

$$j = 1 - \frac{k}{3} \tag{2}$$

Compressive unit stress* in extreme fiber of concrete,

$$f_c = \frac{2M}{jkbd^2} = \frac{2pf_s}{k} \tag{3}$$

Tensile unit stress* in longitudinal reinforcement,

$$f_s = \frac{M}{A_s jd} = \frac{M}{pjbd^2} \tag{4}$$

Steel ratio for balanced reinforcement,

$$p = \frac{1}{2} \frac{1}{\frac{f_s}{f_c}\left(\frac{f_s}{nf_c} + 1\right)} \tag{5}$$

For formulas on shear and bond, see Sections 121 to 127 and 135 to 137.

(b) *Reinforced for Both Tension and Compression:*

Position of neutral axis,

$$k = \sqrt{2n\left(p + p'\frac{d'}{d}\right) + n^2(p + p')^2} - n(p + p') \tag{6}$$

Position of resultant compression,

$$z = \frac{\frac{1}{3}k^3d + 2p'nd'\left(k - \frac{d'}{d}\right)}{k^2 + 2p'n\left(k - \frac{d'}{d}\right)} \tag{7}$$

Arm* of resisting couple,

$$jd = d - z \tag{8}$$

Compressive unit stress in extreme fiber of concrete,

$$f_c = \frac{6M}{bd^2\left[3k - k^2 + \frac{6p'n}{k}\left(k - \frac{d'}{d}\right)\left(1 - \frac{d'}{d}\right)\right]} \tag{9}$$

Tensile unit stress in longitudinal reinforcement,

$$f_s = \frac{M}{pjbd^2} = nf_c \frac{1 - k}{k} \tag{10}$$

Compressive unit stress in longitudinal reinforcement,

$$f'_s = nf_c \frac{k - \frac{d'}{d}}{k} \tag{11}$$

105. *Notation.*—The symbols† used in Formulas (1) to (23) are defined as follows:

- A_s = effective cross-sectional area of metal reinforcement in tension in beams;
- b = width of rectangular beam or width of flange of T-beam;
- d = depth from compression surface of beam or slab to center of longitudinal tension reinforcement;
- d' = depth from compression surface of beam or slab to center of compression reinforcement;
- f_c = compressive unit stress in extreme fiber of concrete;
- f_s = tensile unit stress in longitudinal reinforcement;
- f'_s = compressive unit stress in longitudinal reinforcement;
- h = unsupported length of column;
- I = moment of inertia of a section about the neutral axis for bending;
- j = ratio of lever arm of resisting couple to depth, d;
- k = ratio of depth of neutral axis to depth, d;
- l = span length of beam or slab (generally distance from center to center of supports, see Section 106);
- M = bending moment or moment of resistance in general;
- $n = \frac{E_s}{E_c}$ = ratio of modulus of elasticity of steel to that of concrete;
- p = ratio of effective area of tension reinforcement to effective area of concrete in beams $= \frac{A_s}{bd}$;
- p' = ratio of effective area of compression reinforcement to effective area of concrete in beams;
- w = uniformly distributed load per unit of length of beam or slab;
- z = depth from compression surface of beam or slab of resultant of compressive stresses.

* For f_s = 16,000 to 18,000 lb. per sq. in. and f_c = 800 to 900 lb. per sq. in., j may be assumed as 0.86. For values of pn varying from 0.04 to 0.24, jk is approximately equal to $0.67\sqrt[3]{pn}$.

† For illustration of notation as applied to typical beams or slabs, see Figs. 1 and 2.

106. *Span Length.*—The span length, l, of freely supported beams and slabs shall be the distance between centers of the supports, but shall not exceed the clear span plus the depth of beam or slab. The span length for continuous or restrained beams built to act integrally with supports shall be the clear distance between faces of supports. Where brackets having a width not less than the width of the beam and making an angle of 45° or more with the horizontal axis of a restrained beam are built to act integrally with the beam and support, the span shall be measured from the section where the combined depth of the beam and bracket is at least one-third (1/3) more than the depth of the beam, but no portion of such a bracket shall be considered as adding to the effective depth of the beam. Maximum negative moments are to be considered as existing at the ends of the span, as defined above.

107. *Slightly Restrained Beams of Equal Span.*—Beams and slabs of equal spans built to act integrally with beams, girders, or other slightly restraining supports and carrying uniformly distributed loads shall be designed for the following moments at critical sections:

(a) Beams and slabs of one span,
Maximum positive moment near center,

$$M = \frac{wl^2}{8} \quad (12)$$

(b) Beams and slabs continuous for two spans only,
1. Maximum positive moment near center,

$$M = \frac{wl^2}{10} \quad (13)$$

2. Negative moment over interior support,

$$M = \frac{wl^2}{8} \quad (14)$$

(c) Beams and slabs continuous for more than two spans,
1. Maximum positive moment near center and negative moment at support of interior spans,

$$M = \frac{wl^2}{12} \quad (15)$$

2. Maximum positive moment near centers of end spans and negative moment at first interior support,

$$M = \frac{wl^2}{10} \quad (16)$$

(d) Negative moment at end supports for Cases (a), (b), and (c) of this Section,

$$M = \text{not less than } \frac{wl^2}{16} \quad (16a)$$

108. *Beams Built into Brick or Masonry Walls.*—Beams and slabs built into brick or masonry walls in a manner which develops partial end restraint shall be designed for a negative moment at the support of,

$$M = \text{not less than } \frac{wl^2}{16} \quad (17)$$

109. *Freely Supported Beams of Equal Span.*—Beams and slabs of equal spans freely supported and assumed to carry uniformly distributed loads shall be designed for the moments specified in Section 107, except that no reinforcement for negative moment need be provided at end supports where effective measures are taken to prevent end restraint. The span shall be taken as defined in Section 106 for freely supported beams.

110. *Restrained Beams of Equal Span.*—Beams and slabs of equal span built to act integrally with columns, walls, or other restraining supports and assumed to carry uniformly distributed loads, shall be designed (except as provided in Section 107) for the following moments at critical sections:

(a) Interior spans,
1. Negative moment at interior supports except the first,

$$M = \frac{wl^2}{12} \quad (18)$$

2. Maximum positive moment near centers of interior spans,

$$M = \frac{wl^2}{16} \quad (19)$$

(b) End spans of continuous beams and beams of one span in which $\frac{I}{l}$ is less than twice the sum of the values of $\frac{I}{h}$ for the exterior columns above and below which are built into the beams:
1. Maximum positive moment near center of span and negative moment at first interior supports,

$$M = \frac{wl^2}{12} \quad (20)$$

2. Negative moment at exterior supports

$$M = \frac{wl^2}{12} \quad (21)$$

(c) End spans of continuous beams, and beams of one span, in which $\frac{I}{l}$ is equal to or greater than twice the sum of the values of $\frac{I}{h}$ for the exterior columns above:

1. Maximum positive moment near center of span and negative moment at first interior support,

$$M = \frac{wl^2}{10} \qquad (22)$$

2. Negative moment at exterior support,

$$M = \frac{wl^2}{16} \qquad (23)$$

111. *Continuous Beams of Unequal Spans or with Non-Uniform Loading.*—Continuous beams with unequal spans, or with other than uniformly distributed loading, whether freely supported or restrained, shall be designed for the actual moments under the conditions of loading and restraint.

Provision shall be made where necessary for negative moment near the center of short spans which are adjacent to long spans, and for the negative moment at the end supports, if restrained.

112. *Unsupported Flange Length.*—The distance between lateral supports of the compression area of a beam shall not exceed twenty-four (24) times the least width of compression flange.

C. Flexure of Reinforced Concrete T-Beams

113. *Flexure Formulas.*—Computations of flexure in reinforced concrete T-beams shall be based on the following formulas:

(a) *Neutral Axis in the Flange:*

Use formulas for rectangular beams and slabs in Section 104.

(b) *Neutral Axis below the Flange:*

Position of neutral axis,

$$kd = \frac{2ndA_s + bt^2}{2nA_s + 2bt} \qquad (24)$$

Position of resultant compression,

$$z = \left(\frac{3kd - 2t}{2kd - t}\right)\frac{t}{3} \qquad (25)$$

Arm of resisting couple,

$$jd = d - z \qquad (26)$$

Compressive unit stress in extreme fiber of concrete,

$$f_c = \frac{Mkd}{bt(kd - \frac{1}{2}t)jd} = \frac{f_s}{n}\left(\frac{k}{1-k}\right) \qquad (27)$$

Tensile unit stress in longitudinal reinforcement,

$$f_s = \frac{M}{A_sjd} \qquad (28)$$

Formulas (24), (25), (26), (27), and (28) neglect compression in the stem.*

114. *Notation.*—The symbols† used in Formulas (24) to (28) are defined in Section 105 except as follows:

b' = width of stem of T-beam:

t = thickness of flange of T-beam.

115. *Flange Width.*—Effective and adequate bond and shear resistance shall be provided in beam-and-slab construction at the junction of the beam and slab; the slab shall be built and considered an integral part of the beam; the effective flange width to be used in the design of symmetrical T-beams shall not exceed one-fourth (¼) of the span length of the beam, and its over-hanging width on either side of the web shall not exceed eight (8) times the thickness of the slab nor one-half (½) the clear distance to the next beam.

* The following formulas take into account the compression in the stem; they are recommended where the flange is small compared with the stem:

Position of neutral axis,

$$kd = \sqrt{\frac{2ndA_s + (b - b')t^2}{b'} + \left(\frac{nA_s + (b - b')t}{b'}\right)^2} - \frac{nA_s + (b - b')t}{b'} \qquad (24a)$$

Position of resultant compression,

$$z = \frac{(kdt^2 - \frac{2}{3}t^3)b + [(kd - t)^2(t + \frac{1}{3}(kd - t))]b'}{t(2kd - t)b + (kd - t)^2b'} \qquad (25a)$$

Arm of resisting couple (see footnote, Section 106),

$$jd = d - z \qquad (26a)$$

Compressive unit stress in extreme fiber of concrete,

$$f_c = \frac{2Mkd}{[(2kd - t)bt + (kd - t)^2b']jd} \qquad (27a)$$

Tensile unit stress in longitudinal reinforcement,

$$f_s = \frac{M}{A_sjd} \qquad (28a)$$

† For illustration of certain symbols as applied to typical T-beams, see Fig. 3.

For beams having a flange on one side only, the effective flange width to be used in design shall not exceed one-tenth (1/10) of the span length of the beam, and its overhanging width from the face of the web shall not exceed six (6) times the thickness of the slab nor one-half (1/2) the clear distance to the next beam.

116. *Transverse Reinforcement.*—Where the principal slab reinforcement is parallel to the beam, transverse reinforcement, not less in amount than 0.3 % of the sectional area of the slab, shall be provided in the top of the slab and shall extend across the beam and into the slab not less than two-thirds (2/3) of the width of the effective flange overhang. The spacing of the bars shall not exceed 18 in.

117. *Compressive Stress at Supports.*—Provision shall be made for the compressive stress at the support in continuous T-beam construction.

118. *Shear.*—The flange of the beam shall not be considered as effective in computing the shear and diagonal tension resistance of T-beams.

119. *Isolated Beams.*—Isolated beams, in which the T-form is used only for the purpose of providing additional compression area, shall have a flange thickness not less than one-half (1/2) the width of the web and a total flange width not more than four (4) times the web thickness.

D. Diagonal Tension and Shear

120. *Notation.*—The symbols used in Formulas (29) to (35) are defined in Section 105, except as follows:

A_v = total area, of web reinforcement in tension within a distance, s, that is, $s_1, s_2, s_3 \ . \ . \ . \ s_n$ or the total area of all bars bent up in any one plane;

α = angle between web bars and longitudinal bars;

F = total tension in a bar;

f_c' = ultimate compressive strength of concrete at the age of 28 days, based on tests of 6 by 12-in. or 8 by 16-in. cylinders made and tested in accordance with the "Standard Methods of Making and Storing Specimens of Concrete in the Field." Serial Designation: C31-21) of the American Society for Testing Materials and the "Tentative Methods of Making Compression Tests of Concrete" (Serial Designation: C39-21T) of the American Society for Testing Materials.

f_v = tensile unit stress in web reinforcement;

Q = ratio of the average to the maximum bond stress computed by Formula (31) within the distance, y;

Σo = sum of perimeters of bars in one set;

r = ratio of cross-sectional area of negative reinforcement which crosses entirely over the column capital of a flat slab or over the dropped panel, to the total cross-sectional area of the negative reinforcement in the two column strips;

s = spacing of web bars or stirrups measured at the plane of the lower reinforcement and in the direction of the longitudinal axis of the beam;

t_1 = thickness of flat slab without dropped panels or thickness of a dropped panel (see Fig. 14);

t_2 = thickness of flat slab with dropped panels at points away from the dropped panel (see Fig. 14);

u = bond stress per unit of area of surface of bar;

v = shearing unit stress;

V = total shear;

x = length of bar added for anchorage, including the hook, if any;

y = distance from the point at which tension is computed to the point of beginning of anchorage.

121. *Formula for Shear.*—The shearing unit stress, v, in reinforced concrete beams shall be taken as not less than that computed by Formula (29).*

$$v = \frac{V}{bjd} \qquad (29)$$

122. *Variation of Shear in Beams with Uniform Load.*—For purpose of design of beams carrying uniform loads, not less than one-fourth (1/4) of the total shearing resistance required at either end of the span shall be provided at the section where the computed shearing stress is zero; from that section to the ends of the span the required shearing resistance shall be assumed to vary uniformly.

123. *Width of Beams in Shear Computations.*—The shearing unit stress shall be computed on the minimum width of rectangular beams and on the minimum thickness of the web in beams of I- or T-section.

124. *Shear in Beam and Tile Construction.*—The width of the effective section for shear as governing diagonal tension shall be assumed as the thickness of the concrete web plus one-half (1/2) the thickness of the vertical webs of the concrete or clay tile in contact with the beam. (For typical design, see Fig. 13.)

* For I- or T-beams, b is the width of the stem as given in Section 123.

125. *Types and Spacing of Web Reinforcement.*—Web reinforcement may consist of:

(a) Vertical stirrups or web reinforcing bars.

(b) Inclined stirrups or web reinforcing bars forming an angle of 30° or more with the longitudinal bars.

(c) Longitudinal bars bent up at an angle of 15° or more with the direction of the longitudinal bars.

Stirrups or bent-up bars which are not anchored at both ends, according to the provisions of Section 141, shall not be considered effective as web reinforcement. When the shearing stress is not greater than $0.06f_c'$, the distance, s, measured in the direction of the axis of the beam between two successive stirrups, or between two successive points of bending up of bars, or from the point of bending up of a bar to the edge of the support, shall not be greater than

$$s = \frac{45d}{\alpha + 10} \tag{30}$$

in which the angle, α, is in degrees.

When the shearing stress is greater than $0.06f_c'$, the distance, s, shall not be greater than two-thirds (⅔) of the values given by Formula (30).

126. *Anchorage of Web Reinforcement.*—See Section 141.

127. *Beams without Special Anchorage of Longitudinal Reinforcement.*—The shearing unit stress computed by Formula (29) in beams in which the longitudinal reinforcement is without special anchorage shall not exceed the values given by Formulas (31) and (32) and in no case shall it exceed $0.06f_c'$.

When α is between 45° and 90°,

$$v = 0.02f_c' + \frac{f_v A_v}{bs \sin \alpha} \tag{31}$$

When α is less than 45°,

$$v = 0.02f_c' + \frac{f_v A_v}{bs} (\sin \alpha + \cos \alpha) \tag{32}$$

128. *Beams with Special Anchorage of Longitudinal Reinforcement.*—The shearing unit stress computed by Formula (29) in beams in which longitudinal reinforcement is anchored by means of hooked ends or otherwise, as specified in Section 140, shall not exceed the value given by Formulas (31) and (32), when $0.03f_c'$ is substituted for $0.02f_c'$ in those formulas; in no case shall the shearing unit stress exceed $0.12f_c'$.

129. *Beams with Bars Bent Up at a Single Point.*—Where the web reinforcement consists of bars bent up at a single point, the point of bending shall be at a distance, s, from the edge of the support, not greater than that given in Section 125 and the value of the quantity, $\frac{f_v A_v}{bs} (\sin \alpha + \cos \alpha)$, used in the design shall not exceed 75 lb. per sq. in. (See Fig. 10.)

130. *Combined Web Reinforcement.*—Where two or more types of web reinforcement are used in conjunction, the total shearing resistance of the beam shall be assumed as the sum of the shearing resistances computed for the various types separately. In such computations the shearing resistance of the concrete (the term, $0.02f_c'$ in Formulas (31) and (32)) shall be included only once. In no case shall the maximum shearing stresses be greater than the limiting values given in Sections 127 and 128.

131. *Shearing Stress in Flat Slabs.*—The shearing unit stress in flat slabs shall not exceed the value of v given by Formula (33):

$$v = 0.02f_c'(1 + r) \tag{33}$$

and shall not in any case exceed $0.03f_c'$.

The shearing unit stress shall be computed on:

(a) A vertical section which has a depth, in inches, of ¾ ($t_1 - 1\frac{1}{2}$) and which lies at a distance, in inches, of $t_1 - 1\frac{1}{2}$ from the edge of the column capital; and

(b) A vertical section which has a depth, in inches, of ¾ ($t_2 - 1\frac{1}{2}$) and which lies at a distance, in inches, of $t_2 - 1\frac{1}{2}$ from the edge of the dropped panel.

In no case shall r be less than 0.25. Where the shearing stress computed as in Section (a) is being considered, r shall be assumed as the proportional amount of the negative reinforcement, within the column strip, crossing the column capital. Where the shearing stress computed as in Section (b) is being considered, r shall be assumed as the proportional amount of the negative reinforcement, within the column strip, crossing entirely over the dropped panel.* (For typical flat slab and designation of principal design sections, see Figs. 14 and 15.)

132. *Shear and Diagonal Tension in Footings.*—The shearing stress shall be taken as not less than that computed by Formula (29). The stress on the critical section, shall not exceed $0.02f_c'$ for footings with straight reinforcement bars, nor $0.03f_c'$ for footings in which the reinforcement bars are anchored at both ends by adequate hooks or otherwise as specified in Section 140.

133. *Critical Section for Soil Footings.*—The critical section for diagonal tension in footings on soil shall be computed on a vertical section through the perimeter of the lower base of a frustum of a cone or

* In special cases, where supported by satisfactory engineering analysis, diagonal tension reinforcement may be used and increased shearing stresses allowed in accordance with Sections 127 to 130.

pyramid which has a base angle of 45°, and which has for its top the base of the column or pedestal and for its lower base the plane at the centroid of longitudinal reinforcement.

134. *Critical Section for Pile Footings.*—The critical section for diagonal tension in footings on piles shall be computed on a vertical section at the inner edge of the first row of piles entirely outside a section midway between the face of the column or pedestal and the section described in Section 133 for soil footings, but in no case outside of the section described in Section 133. The critical section for piles not arranged in rows shall be taken midway between the face of the column and the perimeter of the base of the frustum described in Section 133.

E. Bond and Anchorage

135. *Bond Stresses by Beam Action.*—Where bar reinforcement is used to resist tensile stresses developed by beam action, the bond stress shall be taken as not less than that computed by Formula (34):

$$u = \frac{V}{\Sigma ojd} \tag{34}$$

For continuous or restrained members, the critical section for bond for the positive reinforcement shall be assumed to be at the point of inflection; that for the negative reinforcement shall be assumed to be at the face of the support, and at the point of inflection. For simple beams or freely supported end spans of continuous beams the critical section for bond shall be assumed to be at the face of the support.

Bent-up longitudinal bars which, at the critical section, are within a distance, $\frac{d}{3}$, from horizontal reinforcement under consideration, may be included with the straight bars in computing Σo.

In footings only the bars specified in Section 177 as effective in resisting bending moment shall be considered as resisting bond stresses. Special investigation shall be made of bond stresses in footings with stepped or sloping upper surface, as maximum bond stresses may occur at the vertical plane of the steps or near the edges of the footing.

136. *Bond Stress for Ordinary Anchorage.*—In beams where the ordinary anchorage described in Section 139 is provided, the bond stress computed by Formula (34) at any section shall not exceed the following values:

For plain bars................ $u = 0.04f_c'$
For deformed bars meeting the requirements of Section 23.... $u = 0.05f_c'$

137. *Bond Stresses for Special Anchorage.*—In beams where special anchorage of the bars is provided as specified in Section 140, bond stresses exceeding those specified in Section 136 may be used, provided the total tensile stress at a point of abrupt change in stress or at the point of maximum stress, does not exceed the value of F given by Formula (35):

$$F = Qu\Sigma oy + u\Sigma ox \tag{35}$$

in which,

F = total tension in the bar;
Σo = the perimeter of the bar under consideration;
Q = ratio of the average to the maximum bond stress computed by Formula (34) within the distance, y;
u = permissible bond stress = $0.04f_c'$ for plain and $0.05f_c'$ for deformed bars meeting the requirements of Section 23;
x = the length of bar added for anchorage, including the hook, if any;
y = distance from the point at which the tension is computed to the point of beginning of anchorage.

The length of bar added for anchorage may be either straight or bent. The radius of bend shall not be less than four (4) bar diameters.

138. *Bond Stress for Reinforcement in Two or More Directions.*—The permissible bond stress for footings and similar members in which reinforcement is placed in more than one direction shall not exceed 75 % of the values in Sections 136 and 137.

139. *Ordinary Anchorage Requirements.*—In continuous, restrained or cantilever beams, anchorage of the tensile negative reinforcement beyond the face of the support shall provide for the full maximum tension with bond stresses not greater than those specified in Section 136. Such anchorage shall provide a length of bar not less than the depth of the beam. In the case of end supports which have a width less than three-fourths (¾) of the depth of the beam, the bars shall be bent down toward the support a distance not less than the effective depth of the beam. The portion of the bar so bent down shall be as near to the end of the beam as protective covering permits. (See Fig. 9.) In continuous or restrained beams, negative reinforcement shall be carried to or beyond the point of inflection. Not less than one-fourth (¼) of the area of the positive reinforcement shall extend into the support to provide an embedment of ten (10) or more bar diameters.

In simple beams or freely supported end spans of continuous beams, at least one-fourth (¼) of the area of the tensile reinforcement shall extend along the tension side of the beam and beyond the face of the support to provide an embedment of ten (10) or more bar diameters.

140. *Special Anchorage Requirements.*—Where increased shearing stresses are used as provided in Sections 128 and 132, or increased bond stresses as provided in Section 137 are necessary, special anchorage of all reinforcement in addition to that required in Section 139 shall be provided as follows:

(*a*) In continuous and restrained beams, anchorage beyond points of inflection of one-third (1/3) the area of the negative reinforcement and beyond the face of the support of one-third (1/3) the area of the positive reinforcement, shall be provided to develop one-third (1/3) of the maximum working stress in tension, with bond stresses not greater than those specified in Section 130.

(*b*) At the edges of footings, anchorage for all the bars for one-third (1/3) the maximum working stress in tension, shall be provided within a region where the tension in the concrete, computed as an unreinforced beam, does not exceed 40 lb. per sq. in.

(*c*) In simple beams, or freely-supported end spans of continuous beams, at least one-half (1/2) of the tensile reinforcement shall extend along the tension side of the beam to provide an anchorage beyond the face of the support for one-third (1/3) of the maximum working stress in tension.

141. *Anchorage of Web Reinforcement.*—Web bars shall be anchored at both ends by:

(*a*) Providing continuity with the longitudinal reinforcement; or

(*b*) Bending around the longitudinal bar; or

(*c*) A semi-circular hook which has a radius not less than four (4) times the diameter of the web bar.

Stirrup anchorage shall be so provided in the compression and tension regions of a beam as to permit the development of safe working tensile stress in the stirrup at a point $0.3d$ from either face.*

The end anchorage of a web member not in bearing on the longitudinal reinforcement shall be such as to engage an amount of concrete sufficient to prevent the bar from pulling out. In all cases the stirrups shall be carried as close to the upper and lower surfaces as fireproofing requirements permit. (For typical designs see Figs. 8 and 12.)

F. Flat Slabs

(Two-Way and Four-Way Systems with Rectangular Panels)

142. *Moments in Interior Panels.*—The moment coefficients, moment distribution, and slab thicknesses specified herein are for slabs which have three (3) or more rows of panels in each direction, and in which the panels are approximately uniform in size. Slabs with paneled ceiling or with depressed paneling in the floor shall be considered as coming under the requirements herein given. The symbols used in Formulas (36) to (41) are defined in Section 105, except as indicated in Sections 142, 145, and 155.

In flat slabs in which the ratio of reinforcement for negative moment in the column strip is not greater than 0.01, the numerical sum of the positive and negative moments in the direction of either side of the panel for which tension reinforcement must be provided, shall be assumed as not less than that given by Formula (36):

$$M_0 = 0.09Wl\left(1 - \frac{2c}{3l}\right)^2 \qquad (36)$$

in which,

M_0 = sum of positive and negative bending moments† in either rectangular direction, at the principal design sections of a panel of a flat slab;

c = base diameter of the largest right circular cone which lies entirely within the column (including the capital) the vertex angle of which is 90° and the base of which is 1 1/2 in. below the bottom of the slab or the bottom of the dropped panel (see Fig. 14).

l = span length‡ of flat slab, center to center of columns, in the rectangular direction in which moments are considered;

l_1 = span length‡ of flat slab, center to center of columns, perpendicular to the rectangular direction in which moments are considered; and

W = total dead and live load uniformly distributed over a single panel area.

143. *Principal Design Sections.*—In computing the critical moments in flat slabs subjected to uniform load the following principal design sections shall be used:

(*a*) Section for Negative Moment in Middle Strip: The section beginning at a point on the edge of the panel, $\frac{l_1}{4}$, from the column center and extending in a rectangular direction a distance, $\frac{l_1}{2}$, toward the center of the adjacent column on the same panel edge (See Fig. 15).

* Generally, a properly anchored stirrup the diameter of which does not exceed one-fiftieth (1/50) of the depth of the beam will meet these requirements.

† The sum of the positive and negative moments provided for by this equation is about 72 % of the moment found by rigid analysis based on the principles of mechanics. Extensive tests and experience with existing structures have shown that the requirements here stated will give adequate strength. See "Statical Limitations Upon the Steel Requirement in Reinforced Concrete Flat Slab Floors," by John R. Nichols, *Transactions*, Am. Soc. C. E., Vol. LXXVII (1914), p. 1670, and "Moments and Stresses in Slabs," by Messrs. H. M. Westergaard and W. A. Slater, *Proceedings*, Am. Concrete Inst., Vol. XVII (1921).

‡ The column strip and the middle strip to be used when considering moments in the direction of the dimension, l, are located and dimensioned as shown in Fig. 15. The dimension, l_1, does not always represent the short length of the panel. When moments in the direction of the shorter panel length are considered, the dimensions, l and l_1, are to be interchanged and the strips corresponding to those shown in Fig. 15, but extending in the direction of the shorter panel length are to be considered.

(b) Section for Negative Moment in Column Strip: The section beginning at a point on the edge of the panel, $\frac{l_1}{4}$, from the center of a column and extending in a rectangular direction toward the column to a point, $\frac{c}{2}$, therefrom and thence along a one-quarter (¼) circumference about the column center to the adjacent edge of the panel.

(c) Section for Positive Moment in Middle Strip: The section of a length, $\frac{l_1}{2}$, extending in a rectangular direction across the center of the middle strip.

(d) Section for Positive Moment in Column Strip: The section of length, $\frac{l_1}{4}$, extending in a rectangular direction across the center of the column strip.

144. *Moments in Principal Design Sections.*—The moments in the principal design sections shall be those given in Table 6, except as follows:

(a) The sum of the maximum negative moments in the two columns strips may be greater or less than the values given in Table 6 by not more than 0.03 M_0.

(b) The maximum negative moment and the maximum positive moments in the middle strip and the sum of the maximum positive moments in the two column strips may each be greater or less than the values given in Table 6 by not more than 0.01 M_0.

TABLE 6.—MOMENTS TO BE USED IN DESIGN OF FLAT SLABS*

Strip	Flat slabs without dropped panels		Flat slabs with dropped panels	
	Negative	Positive	Negative	Positive
Slabs with Two-way Reinforcement				
Column strip	0.23 M_0	0.11 M_0	0.25 M_0	0.10 M_0
Two column strips	0.46 M_0	0.22 M_0	0.50 M_0	0.20 M_0
Middle strip	0.16 M_0	0.16 M_0	0.15 M_0	0.15 M_0
Slabs with Four-way Reinforcement				
Column strip	0.25 M_0	0.10 M_0	0.27 M_0	0.095 M_0
Two column strips	0.50 M_0	0.20 M_0	0.54 M_0	0.190 M_0
Middle strip	0.10 M_0	0.20 M_0	0.08 M_0	0.190 M_0

* These are approximately the values which would be obtained by considering one-third (⅓) of the total moment, M_0, as positive and two-thirds (⅔) of it as negative moment.

145. *Thickness of Flat Slabs and Dropped Panels.*—The total thickness,‡ t_1, of the dropped panel, in inches, or of the slab if a dropped panel is not used, shall be not less than:

$$t_1 = 0.038\left(1 - 1.44\frac{c}{l}\right) l \sqrt{Rw'\frac{l_1}{b_1}} + 1\tfrac{1}{2} \qquad (37)\dagger$$

in which,

R = ratio of negative moment in the two column strips to M_0;
w' = uniformly distributed dead and live load per unit of area of floor; and
b_1 = dimension of the dropped panel in the direction parallel to l_1.

For slabs with dropped panels the total thickness,‡ in inches, at points beyond the dropped panel shall be not less than:

$$t_2 = 0.02l\sqrt{w'} + 1 \qquad (38)$$

The slab thickness, t_1 or t_2, shall in no case be less than $\frac{l}{32}$ for floor-slabs, and not less than $\frac{l}{40}$ for roof-slabs. In determining minimum thickness by Formulas (37) and (38), the value of l shall be the pane length, center to center of the columns, on the long side of the panel, l_1 shall be the panel length on the short side of the panel, and b_1 shall be the width or diameter of the dropped panel in the direction of l_1, except that in a slab without a dropped panel, b_1 shall be $0.5l_1$.

‡ The thickness will be in inches regardless of whether l and w' are in feet and pounds per square foot, or in inches and pounds per square inch.

† The values of R used in this formula are the coefficients of M_0 for negative moment in two column strips in Table 6.

146. *Minimum Dimensions of Dropped Panels.*—The dropped panel shall have a length or diameter in each rectangular direction of not less than one-third (1/3) the panel length in that direction, and a thickness not greater than $1.5t_2$.

147. *Wall and Other Irregular Panels.*—In wall panels and other panels in which the slab is discontinuous at the edge of the panel, the maximum negative moment one panel length away from the discontinuous edge and the maximum positive moment between shall be increased as follows:

(*a*) Column strip perpendicular to the wall or discontinuous edge, 15 % greater than that in Table 6.

(*b*) Middle strip perpendicular to wall or discontinuous edge, 30 % greater than that given in Table 6.

In these strips the bars used for positive moments perpendicular to the discontinuous edge shall extend to the edge of the panel at which the slab is discontinuous.

148. *Panels with Marginal Beams.*—In panels having a marginal beam on one edge or on each of two adjacent edges, the beam shall be designed to carry at least the load superimposed directly upon it, exclusive of the panel load. A beam which has a depth greater than the thickness of the dropped panel into which it frames, shall be designed to carry, in addition to the load superimposed upon it, at least one-fourth (1/4) of the distributed load for which the adjacent panel or panels are designed, and each column strip adjacent to and parallel with the beam shall be designed to resist a moment at least one-half (1/2) as great as that specified in Table 6 for a column strip.*

Each column strip adjacent to and parallel with a marginal beam which has a depth less than the thickness of the dropped panel into which it frames shall be designed to resist the moments specified in Table 6 for a column strip. Marginal beams on opposite edges of a panel and the slab between them shall be designed for the entire load and the panels shall be designed as simple beams.

149. *Discontinuous Panels.*—The negative moments on sections at and parallel to the wall, or discontinuous edge of an interior panel, shall be determined by the conditions of restraint.†

150. *Flat Slabs on Bearing Walls.*—Where there is a beam or a bearing wall on the center line of columns in the interior portion of a continuous flat slab, the negative moment at the beam or wall line in the middle strip perpendicular to the beam or wall shall be taken as 30 % greater than the moment specified in Table 6 for a middle strip. The column strip adjacent to and lying on either side of the beam or wall shall be designed to resist a moment at least one-half (1/2) of that specified in Table 6 for a column strip.

151. *Point of Inflection.*—The point of inflection in any line parallel to a panel edge in interior panels of symmetrical slabs without dropped panels shall be assumed to be at a distance from the center of the span equal to 0.30 of the distance between the two sections of critical negative moment at opposite ends of the line; for slabs having dropped panels, the coefficient shall be 0.25.

152. *Reinforcement.*—The reinforcement bars which cross any section and which fulfill the requirements given in Section 153 may be considered as effective in resisting the moment at the section. The sectional area of a bar multiplied by the cosine of the angle between the direction of the axis of the bar and any other direction may be considered effective as reinforcement in that direction.

153. *Arrangement of Reinforcement.*—The design shall include adequate provision for securing the reinforcement in place so as to take not only the critical moments, but the moments at intermediate sections. Provision shall be made for possible shifting of the point of inflection by carrying all bars in rectangular or diagonal directions, each side of a section of critical moment, either positive or negative, to points at least twenty (20) diameters beyond the point of inflection as specified in Section 151. Lapped splices shall not be permitted at or near regions of maximum stress except as described. At least four-tenths (4/10) of all bars in each direction shall be of such length and shall be so placed as to provide reinforcement at two sections of critical negative moment and at the intermediate section of critical positive moment. Not less than one-third (1/3) of the bars used for positive reinforcement in the column strip shall extend into the dropped panel not less than twenty (20) diameters of the bar, or in case no dropped panel is used, shall extend to a point not less than one-eighth (1/8) of the span length from the center line of the column or the support.

154. *Reinforcement at Construction Joints.*—See Section 72.

155. *Tensile Stress in Reinforcement.*—The tensile stress, f_s, in the reinforcement in flat slabs shall be taken as not less than that computed by Formula (39):

$$f_s = \frac{RM_0}{A_s jd} \qquad (39)$$

in which,

RM_0 = moment specified in Section 144 for two column strips or for one middle strip; and

A_s = effective cross-sectional area of the reinforcement which crosses any of the principal design sections and which meets the requirements of Section 153. The stress so computed shall not at any of the principal design sections exceed the values specified in Section 194.

156. *Compressive Stress in Concrete.*—The compressive stress in the concrete in flat slabs shall be taken as not less than that computed by Formulas (40) and (41), but the stress so computed shall not exceed $0.4 f_c'$.

* In wall columns, brackets are sometimes substituted for capitals, or other changes are made in the design of the capital. Attention is directed to the necessity for taking into account the change in the value of c in the moment formula for such cases.

† The Committee is not prepared to make a more definite recommendation at this time.

Compression due to negative moment, RM_0, in the two column strips:

$$f_c = \frac{3.5\ RM_0}{0.67\ \sqrt[3]{pn}\ b_1d^2}\left(1 - 1.2\ \frac{r}{l}\right) \quad (40)$$

in which, b_1 is as specified in Section 145.

Compression due to positive moment, RM_0, in the two column strips, or negative or positive moment in the middle strip:

$$f_c = \frac{6RM_0}{0.67\sqrt[3]{pn}\ l_1d^2} \quad (41)$$

In special cases supported by satisfactory engineering analysis, approved by the Engineer, compression reinforcement may be used to increase the resistance to compression in accordance with other provisions of these specifications.

157. *Shearing Stress.*—See Section 131.

158. *Unusual Panels.*—For structures having a width of one or two panels, and also for slabs having panels of markedly different sizes, an analysis shall be made of the moments developed in both slab and columns, and the values given in Sections 142 to 157 modified accordingly.

159. *Bending Moments in Columns.*—See Section 171.

G. Reinforced Concrete Columns

160. *Limiting Dimensions.*—The following sections on reinforced concrete columns are based on the assumption of a short column. Where the unsupported length is greater than forty (40) times the least radius of gyration (40R), the safe load shall be determined by Formula (47). Principal columns in buildings shall have a minimum diameter or thickness of 12 in. Posts that are not continuous from story to story shall have a minimum diameter or thickness of 6 in.

161. *Unsupported Length.*—The unsupported length of reinforced concrete columns shall be taken as:

(*a*) In flat slab construction the clear distance between the floor and under side of the capital.

(*b*) In beam-and-slab construction, the clear distance between the floor and the under side of the shallowest beam framing into the column at the next higher floor level.

(*c*) In floor construction with beams in one direction only, the clear distance between floor slabs.

(*d*) In columns supported laterally by struts or beams only, the clear distance between consecutive pairs (or groups) of struts or beams, provided that to be considered an adequate support, two such struts or beams shall meet the column at approximately the same level and the angle between the two planes formed by the axis of the column and the axis of each strut, respectively, is not less than 75 nor more than 105 degrees.

When haunches are used at the junction of beams or struts with columns, the clear distance between supports may be considered as reduced by two-thirds (⅔) of the depth of the haunch.

162. *Safe Load on Spiral Columns.*—The safe axial load on columns reinforced with longitudinal bars and closely spaced spirals enclosing a circular core shall be not greater than that determined by Formula (42):*

$$P = A_cf_c + nf_cpA \quad (42)$$

in which,

P = total safe axial load on column the $\frac{h}{R}$ of which is less than 40;

A = area of the concrete core enclosed within the spiral; the diameter of the core (or of the spiral) shall be taken as the distance center to center of the spiral wire;

p = ratio of effective area of longitudinal reinforcement to area of the concrete core;

$A_c = A(1 - p)$ = net area of concrete core;

f_c = permissible compressive stress in concrete =

$$300 + (0.10 + 4_p)f_c' \quad (43)$$

The longitudinal reinforcement shall consist of at least six (6) bars of minimum diameter of ½ in. and its effective cross-sectional area shall not be less than 1 %, nor more than 6 % of the core.

163. *Spiral Reinforcement.*—The spiral reinforcement shall be not less than one-fourth (¼) the volume of the longitudinal reinforcement; it shall consist of evenly spaced continuous spirals held firmly in place and true to line by at least three vertical spacer bars. The spacing of the spirals shall be not greater than one-sixth (⅙) of the diameter of the core and in no case more than 3 in. The spiral reinforcement shall meet the requirements of the "Tentative Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement" (Serial Designation A82–21T) of the American Society for Testing Materials.

164. *Protection of Spirally Reinforced Column.*—Reinforcement shall be protected everywhere by a covering of concrete cast monolithic with the core, which shall have a minimum thickness of 1½ in. in square columns and 2 in. in round or octagonal columns.

165. *Safe Load on Columns with Lateral Ties.*—The safe axial load on columns reinforced with longitudinal bars and separate lateral ties shall be not greater than that determined by Formula (44):

$$P = (A_c' + A_sn)f_c \quad (44)$$

* The symbols used in Formulas (42) to (49) are defined in Section 105, except as indicated in Sections 162, 165, 168, 170, 176, and 182.

in which,

A_c' = net area of concrete in the column (total column area minus area of reinforcement);

A_s = effective cross-sectional area of longitudinal reinforcement;

f_c = the permissible compressive stress in concrete shall not exceed $0.20 f_c'$.

The amount of longitudinal reinforcement considered in the calculations shall be not more than 2 %, nor less than 0.5 % of the total area of the column. The longitudinal reinforcement shall consist of not less than four (4) bars of minimum diameter of ½ in., placed with a clear distance from the face of the column of not less than 2 in.

166. *Lateral Ties.*—Lateral ties shall be not less than ¼ in. in diameter, spaced not more than 8 in. apart.

167. *Bending in Columns.*—Reinforced concrete columns subject to bending stresses shall be treated as follows:

(a) With spiral reinforcement: The compressive unit stress on the concrete within the core area under combined axial load and bending shall not exceed by more than 20 % the value given for axial load by Formula (43).

(b) With lateral ties: Additional longitudinal reinforcement may be used if required, and the compressive unit stress on the concrete under combined axial load and bending may be increased to $0.30 f_c'$. The total amount of reinforcement considered in the computations shall be not more than 4 % of the total area of the column.

Tension in the longitudinal reinforcement due to bending of the column shall not exceed 16,000 lb. per sq. in.

168. *Composite Columns.*—The safe load on composite columns in which a structural steel or cast-iron column is thoroughly encased in a circumferentially reinforced concrete core shall be based on a certain unit stress for the steel or cast-iron core plus a unit stress of $0.25 f_c'$ on the area within the spiral core.

The unit compressive stress on the steel section shall be not greater than that determined by Formula (45):

$$f_r = 18{,}000 - 70\frac{h}{R} \tag{45}$$

but shall not exceed 16,000 lb. per sq. in.

The unit stress on the cast-iron section shall be not greater than that determined by Formulas (46):

$$f_r = 12{,}000 - 60\frac{h}{R} \tag{46}$$

but shall not exceed 10,000 lb. per sq. in. In Formulas (45) and (46),

f_r = compressive unit stress in metal core; and

R = least radius of gyration of the steel or cast-iron section.

The diameter of the cast-iron section shall not exceed one-half (½) of the diameter of the core within the spiral. The spiral reinforcement shall be not less than 0.5 % of the volume of the core within the spiral and shall conform in quality, spacing, and other requirements to the provisions for spirals in Section 163.

Ample section of concrete and continuity of reinforcement shall be provided at the junction with beams or girders. The area of the concrete between the spiral and the metal core shall be not less than that required to carry the total floor load of the story above on the basis of a stress in the concrete of $0.35 f_c'$, unless special brackets are arranged on the metal core to receive directly the beam or slab load.

169. *Structural Steel Columns.*—The safe load on a structural steel column of a section which fully encases an area of concrete and which is protected by an outside shell of concrete at least 3 in. thick, shall be computed in the same manner as for composite columns in Section 168, allowing $0.25 f_c'$ on the area of the concrete enclosed by the steel section. The outside shell shall be reinforced by wire mesh, ties, or spiral hoops, weighing not less than 0.2 lb. per sq. ft. at the surface of the mesh, and with a maximum spacing of 6 in. between strands or hoops. Special brackets shall be used to receive the entire floor load at each story. The safe load in steel columns calculated by Formula (45) shall not exceed 16,000 lb. per sq. in.

170. *Long Columns.*—The permissible working load on the core in axially loaded columns which have a length greater than forty (40) times the least radius of gyration of the column core (40R) shall be not greater than that determined by Formula (47)

$$\frac{P'}{P} = 1.33 - \frac{h}{120R} \tag{47}$$

in which,

P' = total safe axial load on long column;

P = total safe axial load on column of the same section the $\frac{h}{R}$ of which is less than 40, determined as in Sections 162 and 165.

R = least radius of gyration of column core.

171. *Bending Moments in Columns.*—The bending moments in interior and exterior columns shall be determined on the basis of loading conditions and end restraint, and shall be provided for in the design. The recognized methods shall be followed in calculating the stresses due to combined

axial load and bending. In spiral columns, the area to be considered as resisting the stress is the area within the spiral.

II. Footings

172. *General.*—The requirements for tension, compression, shear, and bond in Sections 103 to 141, inclusive, shall govern the design of footings, except as hereinafter provided.

173. *Soil Footings.*—The load per unit of area on soil footings shall be computed by dividing the column load by the area of base of the footing.

174. *Pile Footings.*—Footings on piles shall be treated in the same manner as footings on soil, except that the load shall be considered as concentrated at the pile centers.

175. *Sloped or Stepped Footings.*—Footings in which the thickness has been determined by the requirements for shear as specified in Sections 133 and 134 may be sloped or stepped between the critical section and the edge of the footing, provided that the shear on no section outside the critical section exceeds the value specified, and provided further that the thickness of the footing above the reinforcement at the edge shall not be less than 6 in. for footings on soil nor less than 12 in. for footings on piles. Sloped or stepped footings shall be cast as a unit.

176. *Critical Section for Bending.*—The critical section for bending in a concrete footing which supports a concrete column or pedestal, shall be considered to be at the face of the column or pedestal. Where steel or cast-iron column bases are used, the moment in the footing shall be computed at the middle and at the edge of the base; the load shall be considered as uniformly distributed over the column or pedestal base.

The bending moment at the critical section in a square footing supporting a concentric square column, shall be computed from the load on the trapezoid bounded by one face of the column, the corresponding outside edge of the footing, and the portions of the two diagonals. The load on the two corner triangles of this trapezoid shall be considered as applied at a distance from the face equal to six-tenths (0.6) of the projection of the footing from the face of the column. The load on the rectangular portion of the trapezoid shall be considered as applied at its center of gravity The bending moment is expressed by Formula (48):

$$M = \frac{w}{2}(a + 1.2c)c^2 \qquad (48)$$

in which,

M = bending moment at critical section of footing;
a = width of face of column or pedestal;
c = projection of footing from face of column;
w = upward reaction per unit of area of base of footing.

For a round or octagonal column, the distance, a, shall be taken as equal to the side of a square of an area equal to the area enclosed within the perimeter of the column. (For typical footing designs, see Figs. 16 and 17.)

177. *Reinforcement.*—The reinforcement in each direction in the footing shall be determined as for a reinforced concrete beam; the effective depth shall be the distance from the top of the footing to the plane of the reinforcement. The sectional area of reinforcement shall be distributed uniformly across the footing unless the width is greater than the side of the column or pedestal plus twice the effective depth of the footing, in which case the width over which the reinforcement is spread may be increased to include one-half (½) the remaining width of the footing. In order that no considerable area of the footing shall remain unreinforced, additional reinforcement shall be placed outside of the width specified, but such reinforcement shall not be considered as effective in resisting the calculated bending moment. For the extra reinforcement a spacing double that within the effective belt may be used.

178. *Concrete Stress.*—The extreme fiber tress in compression in the concrete shall be kept within the limits specified in Section 180. The extreme fiber stress in sloped or stepped footings shall be based on the exact shape of the section for a width not greater than that assumed effective for reinforcement.

179. *Irregular Footings.*—A rectangular or irregularly shaped footing shall be computed by dividing it into rectangles or trapezoids tributary to the sides of the column, using the distance to the center of gravity of the area as the moment arm of the upward forces. Outstanding portions of combined footings shall be treated in the same manner. Other portions of combined footings shall be designed as beams or slabs.

180. *Shearing Stresses.*—See Sections 132 to 134.

181. *Bond Stress.*—See Sections 135 to 141.

182. *Transfer of Stress at Base of Column.*—The compressive stress in longitudinal reinforcement at the base of a column shall be transferred to the pedestal or footing by either dowels or distributing bases. When dowels are used, there shall be at least one for each column bar, and the total sectional area of the dowels shall be not less than the sectional area of the longitudinal reinforcement in the column. The dowels shall extend into the column and into the pedestal or footing not less than fifty (50) diameters of the dowel bars for plain bars, or forty (40) diameters for deformed bars.

When metal distributing bases are used, they shall have sufficient area and thickness to transmit safely the load from the longitudinal reinforcement in compression and bending. The permissible com-

pressive unit stress on top of the pedestal or footing directly under the column shall be not greater than that determined by Formula (49):

$$r_a = 0.25 f_c' \sqrt[3]{\frac{A}{A'}} \qquad (49)$$

in which,

r_a = permissible working stress over the loaded area;
A = total area at the top of the pedestal or footing;
A' = loaded area at the column base;
f_c' = ultimate compressive strength of concrete. (See Section 120.)

In sloped or stepped footings, A may be taken as the area of the top horizontal surface of the footing or as the area of the lower base of the largest frustrum of a pyramid or cone contained wholly within the footing and having for its upper base the loaded area, A', having side slopes of 1 vertical to 2 horizontal.

183. *Pedestals Without Reinfocement.*—The allowable compressive unit stress on the gross area of a concentrically loaded pedestal or on the minimum area of a pedestal footing shall not exceed $0.25 f_c'$, unless reinforcement is provided and the member designed as a reinforced concrete column.

The depth of a pedestal or pedestal footing shall be not greater than three (3) times its least width and the projection on any side from the face of the supported member shall be not greater than one-half (½) the depth. The depth of a pedestal the sides of which are sloped or stepped shall not exceed three (3) times the least width or diameter of the section midway between the top and bottom. A pedestal footing supported directly on piles shall have a mat of reinforcing bars having a cross-sectional area of not less than 0.20 sq. in. per ft. in each direction, placed 3 in. above the top of the piles.

I. Reinforced Concrete Retaining Walls

184. *Loads and Unit Stresses.*—Reinforced concrete retaining walls shall be so designed* that the permissible unit stresses specified in Sections 186 to 197 are not exceeded. The heels of cantilever, counterforted, and buttressed retaining walls shall be proportioned for maximum resultant vertical loads, but when the foundation reaction is neglected, the permissible unit stresses shall not be more than 50 % greater than the normal permissible stresses.

185. *Details of Design.*—The following principles shall be followed in the design of reinforced concrete retaining walls:

(*a*) The unsupported toe and heel of the base slabs shall be considered as cantilever beams fixed at the edge of the support.

(*b*) The vertical section of a cantilever wall shall be considered as a cantilever beam fixed at the top of the base.

(*c*) The vertical sections of counterforted and buttressed walls and parts of base slabs supported by the counterforts or buttresses shall be designed in accordance with the requirements for a continuous slab in Section 110.

(*d*) The exposed faces of walls without buttresses shall preferably be given a batter of not less than ¼ in. per ft.

(*e*) Counterforts shall be designed in accordance with the requirements for T-beams in Section 113 to 115. Stirrups shall be provided in the counterforts to take the reaction when the tension reinforcement of the face walls and heels of bases is designed to span between the counterforts. Stirrups shall be anchored as near the exposed face of the longitudinal wall and as close to the lower face of the base as the requirements for protective covering permit.

(*f*) Buttresses shall be designed in accordance with the requirements specified for rectangular beams.

(*g*) The shearing stress at the junction of the base with counterforts or buttresses shall not exceed the values specified in Sections 120 to 130.

(*h*) Horizontal metal reinforcement shall be of such form and distributed so as to develop the required bond. To prevent temperature and shrinkage cracks in exposed surface not less than 0.25 sq. in. of horizontal metal reinforcement per foot of height shall be provided.

(*i*) Grooved lock-joints shall be placed not more than 60 ft. apart to care for temperature changes.

(*j*) Counterforts and buttresses shall be located under all points of concentrated loading, and at intermediate points as may be required by the design.

(*k*) The walls shall be cast as a unit between expansion joints unless construction joints formed in accordance with Sections 69 and 73 are provided.

(*l*) Drains or "weep-holes" not less than 4 in. in diameter and not more than 10 ft. apart, shall be provided; at least one drain shall be provided for each pocket formed by counterforts.

J. Summary of Working Stresses

186. *General.*—The following notation shall be used, in which,

f_c' = ultimate compressive strength of concrete at age of 28 days, based on tests of 6 by 12-in. or 8 by 16-in. cylinders made and tested in accordance with the "Standard Methods of Making and Storing Specimens of Concrete in the Field" (Serial Designation: C31–21) of the American Society for Testing Materials and the "Tentative Methods of Making Compressive Tests of Concrete" (Serial Designation: C39–21T) of the American Society for Testing Materials.

* In proportioning retaining walls consideration should be given to: (*a*) Bearing value of soil; and (*b*) stability against sliding.

Direct Stress in Concrete

187. ***Direct Compression.—***
(a) Columns the length of which does not exceed 40*R*:
1. With spirals . . . varies with amount of longitudinal reinforcement.... (See Section 162.)
2. Longitudinal reinforcement and lateral ties.......................... (See Section 165.)
(b) Long columns.. (See Section 170.)
(c) Piers and pedestals.................................... $0.25f_c'$ (See Section 183.)
188. ***Compression in Extreme Fiber.—***
(a) Extreme fiber stress in flexure.. $0.40f_c'$
(b) Extreme fiber stress in flexure adjacent to supports of continuous beams.......... $0.45f_c'$
189. ***Tension.—***
In concrete members.. None

Shearing Stresses in Concrete

190. ***Longitudinal Bars without Special Anchorage.—***
(a) Beams without web reinforcement... $0.02f_c'$
(b) Beams with stirrups or bent-up bars or combination of the two .... $0.06f_c'$
191. ***Longitudinal Bars Having Special Anchorage.—***
(a) Beams without web reinforcement... $0.03f_c'$
(b) Beams with stirrups or bent-up bars or a combination of the two .... $0.12f_c'$
192. ***Flat Slabs.—***
(a) Shear at distance, *d*, from capital or dropped panel .... $0.03f_c'$
(b) Other limiting cases in flat slabs.............................. (See Section 131.)
193. ***Footings.—***
(a) Longitudinal bars without special anchorage........................ $0.02f_c'$
(b) Longitudinal bars having special anchorage.............................. $0.03f_c'$

Stresses in Reinforcement

194. ***Tension in Steel.—***
(a) Billet-steel bars:
1. Structural steel grade.............................. 16,000 lb. per sq. in.
2. Intermediate grade................................. 18,000 lb. per sq. in.
3. Hard grade... 18,000 lb. per sq. in.
(b) Rail-steel bars..................................... 18,000 lb. per sq. in.
(c) Structural steel...................................... 16,000 lb. per sq. in.
(d) Cold-drawn steel wire:
1. Spirals.. Stress not calculated
2. Elsewhere.. 18,000 lb. per sq. in.
195. ***Compression in Steel.—***
(a) Bars.................................... Same as Section 194 (*a*) and (*b*)
(b) Structural steel core of composite column.............. 16,000 lb. per sq. in.
Reduced for slenderness ratio.......................... (See Section 168.)
(c) Structural steel column................................ 16,000 lb. per sq. in.
Reduced for slenderness ratio .... (See Section 169.)
196. ***Compression in Cast Iron.—***
Composite cast-iron column.................................. 10,000 lb. per sq. in.
Reduced for slenderness ratio. .... (See Section 168.)
197. ***Bond Between Concrete and Reinforcement.—***
(a) Beams and slabs, plain bars.. $0.04f_c'$
(b) Beams and slabs, deformed bars. .... $0.05f_c'$
(c) Footings, plain bars, one-way.. $0.04f_c'$
(d) Footings, deformed bars, one-way.. $0.05f_c'$
(e) Footings, bars, two-ways.............. Sections (*c*) or (*d*) reduced by 25 per cent.

Notation and Figures

All symbols used in the Standard Specifications for Concrete and Reinforced Concrete have been collected here for convenience of reference. The symbols are in general defined in the text near the formulas in which they are used. In a few instances the same symbol is used in distin however, there is little danger of confusion from this source.

Notation

a = width of face of column or pedestal;
α = angle between inclined web bars and longitudinal bars;

A = total net area of column, footing, or pedestal, exclusive of fireproofing;
A' = loaded area of pedestal, pier, or footing;
A_c = $A(1 - p)$ = net area of concrete core of column (core area minus area of reinforcement);
A_c' = net area of concrete in columns with lateral ties (total column area minus area of reinforcement);
A_s = effective cross-sectional area of metal reinforcement in tension in beams or compression in columns, and the effective cross-sectional area of metal reinforcement which crosses any of the principal design sections of a flat slab and which meets the requirements of Section 153;
A_v = total area of web reinforcement in tension within a distance of s (s_1, s_2, s_3, etc.), or the total area of all bars bent up in any one plane (see Fig. 9);
b = width of rectangular beam or width of flange of T-beam;
b' = width of stem of T-beam;
b_1 = dimension of the dropped panel of a flat slab in the direction parallel to l_1;*
c = base diameter of the largest right circular cone which lies entirely within the column (including the capital) the vertex angle of which is 90° and the base of which is 1½ in. below the bottom of the slab or the bottom of the dropped panel (see Fig. 14);
c = projection of footing from face of column;
C = total compressive stress in concrete;
C' = total compressive stress in reinforcement;
d = depth from compression surface of beam or slab to center of longitudinal tension reinforcement;
d' = depth from compression surface of beam or slab to center of compression reinforcement;
E_c = modulus of elasticity of concrete in compression;
E_s = modulus of elasticity of steel in tension = 30,000,000 lb. per sq. in.;
f_c = compressive unit stress in extreme fiber of concrete;
f_c' = ultimate compressive strength of concrete at age of 28 days, based on tests of 6 by 12-in. or 8 by 16-in. cylinders made and tested in accordance with the "Standard Methods of Making and Storing Specimens of Concrete in the Field" and the "Tentative Methods of Making Compression Tests of Concrete";
f_r = compressive unit stress in metal core;
f_s = tensile unit stress in longitudinal reinforcement;
f_s' = compressive unit stress in longitudinal reinforcement;
f_v = tensile unit stress in web reinforcement;
F = total tension in a bar;
h = unsupported length of column;
I = moment of inertia of a section about the neutral axis for bending;
j = ratio of lever arm of resisting couple of depth, d;
jd = $d - z$ = arm of resisting couple;
k = ratio of neutral axis to depth, d;
l = span length of beam or slab (generally distance from center to center of supports; for special cases, see Sections 106 and 145);
l = span length of flat slab, center to center of columns; in the rectangular direction in which moments are considered;*
l_1 = span length of flat slab, center to center of columns, perpendicular to the rectangular direction in which moments are considered;*
M = bending moment or moment of resistance in general;
M_0 = sum of positive and negative bending moments in either rectangular direction, at the principal design sections of a panel of a flat slab;
$n = \frac{E_s}{E_c}$ = ratio of modulus of elasticity of steel to that of concrete;
Σo = sum of perimeters of bars in one set;
p = ratio of effective area of tension reinforcement to effective area of concrete in beams = $\frac{A_s}{bd}$; and the ratio of effective area of longitudinal reinforcement to the area of the concrete core in columns;
p' = ratio of effective area of compression reinforcement to effective area of concrete in beams;
P = total safe axial load on column the $\frac{h}{R}$ of which is less than 40;
P' = total safe axial load on long column;

* In flat-slab design, the column strip, and the middle strip to be used when considering moments in the direction of the dimension, l, are located and dimensioned as shown in Fig. 15. The dimension, l_1, does not always represent the short length of the panel. When moments in the direction of the shorter panel length are considered, the dimensions, l and l_1, are to be interchanged and strips corresponding to those shown in Fig. 15, but extending in the direction of the shorter panel length, are to be considered.

Q = ratio of the average to the maximum bond stress computed by Formula (34) within the distance, y;

r = ratio of cross-sectional area of negative reinforcement which crosses entirely over the column capital of a flat slab or over the dropped panel, to the total cross-sectional area of the negative reinforcement in the two column strips;

r_a = permissible working stress in concrete over the loaded area of a pedestal, pier, or footing;

R = ratio of positive or negative moment in two column strips or one middle strip of a flat slab, to M_0;

R = least radius of gyration of a section;

s = spacing of web members, measured at the plane of the lower reinforcement and in the direction of the longitudinal axis of the beam;

t = thickness of flange of T-beam;

t_1 = thickness of flat slab without dropped panels or thickness of a dropped panel (see Fig. 14);

t_2 = thickness of flat slab with dropped panels at points away from the dropped panel (see Fig. 14);

T = total tensile stress in longitudinal reinforcement;

u = bond stress per unit of area of surface of bar;

v = shearing unit stress;

V = total shear;

w = uniformly distributed load per unit of length of beam or slab;

w = upward reaction per unit of area of base of footing;

w' = uniformly distributed dead and live load per unit of area of a floor or roof;

W = total dead and live load uniformly distributed over a single panel area;

x = length of bar added for anchorage, including the hook, if any,

y = distance from the point at which the tension is computed to the point of beginning of anchorage;

z = depth from compression surface of beam or slab to resultant of compressive stresses.

Figures

For explanation of symbols used in figures, see the foregoing notation.

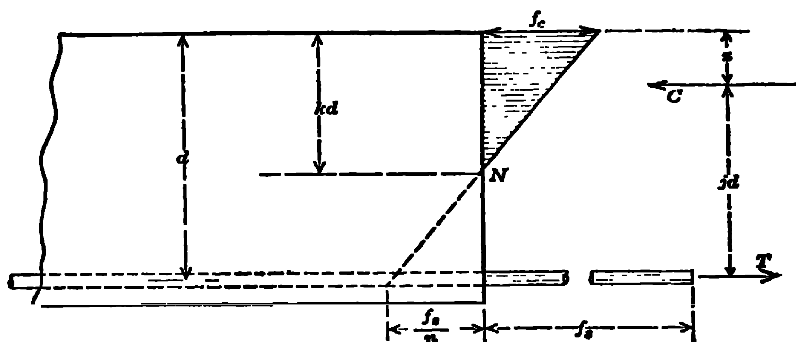


Fig. 1.—Nomenclature for concrete beam reinforced for tension.

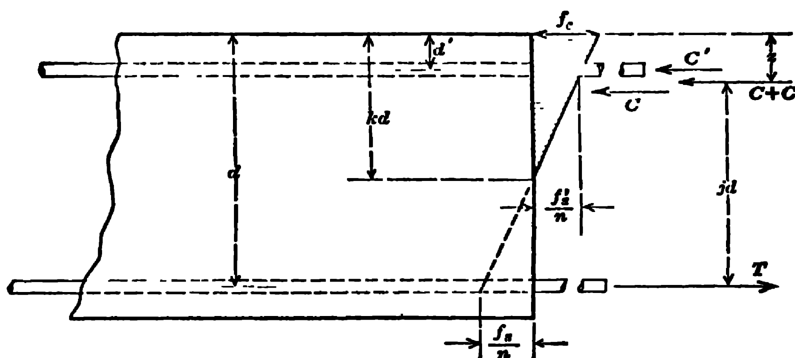


Fig. 2.—Nomenclature for concrete beam reinforced for tension and compression.

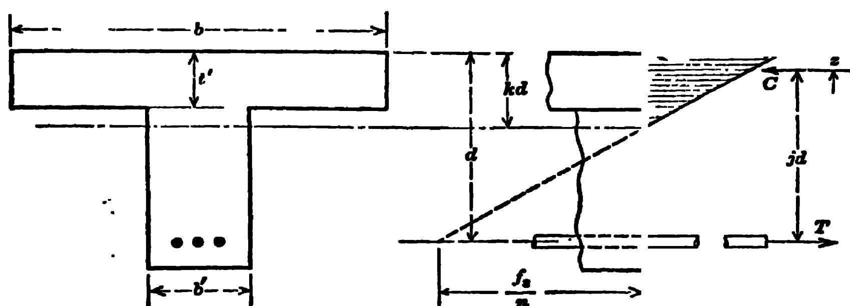


Fig. 3.—Nomenclature for reinforced concrete T-beam.

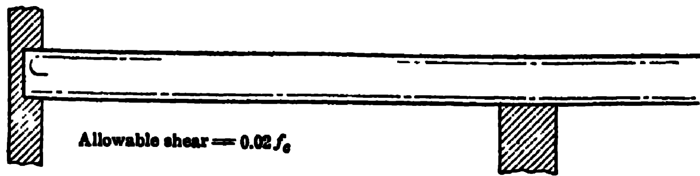


Fig. 4.—Typical reinforced concrete beam; principal longitudinal bars without special anchorage.

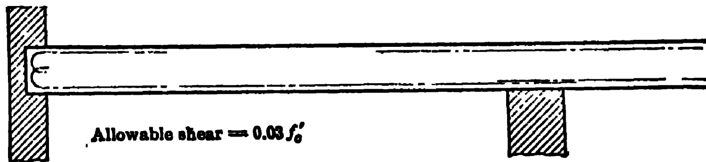


Fig. 5.—Typical reinforced concrete beam; special anchorage of longitudinal bars.

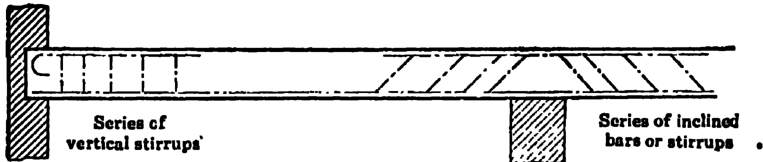


Fig. 6.—Typical reinforced concrete beam without special anchorage; web reinforced by means of series of vertical stirrups or series of inclined bars or stirrups.

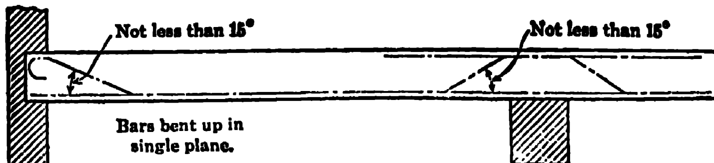


Fig. 7.—Typical reinforced concrete beam; principal longitudinal bars bent up in single plane.

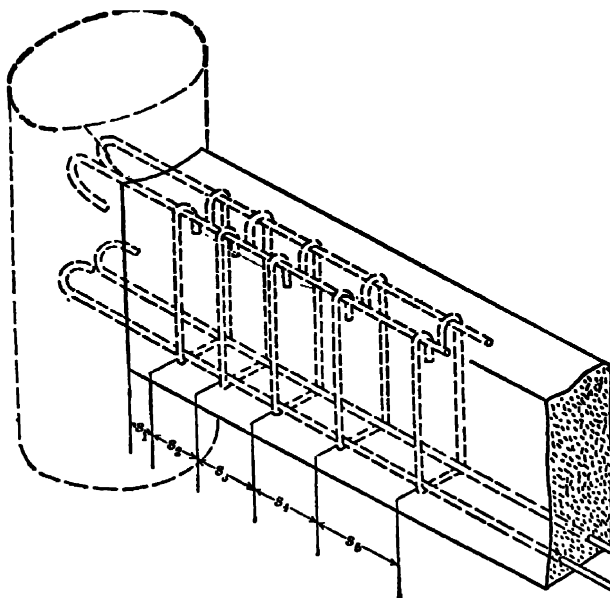


Fig. 8.—Typical reinforced concrete beam with anchored longitudinal bars and vertical stirrups.

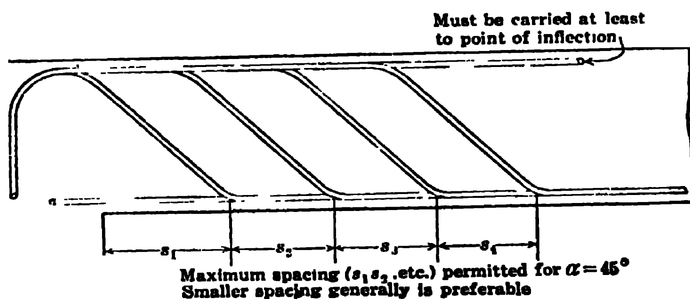


Fig. 9.—Typical beam with web reinforced by means of series of inclined bars.

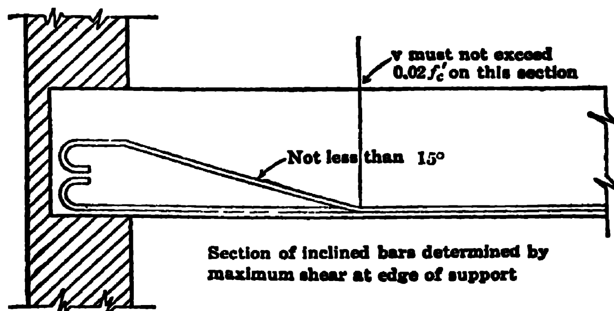


Fig. 10.—Typical beam with web reinforced by means of bars bent up in a single plane.

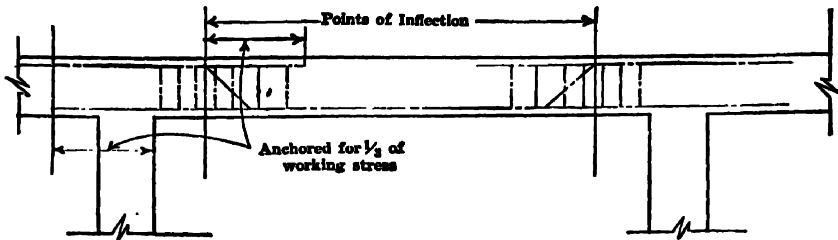


FIG. 11.—Typical web reinforcement for continuous beams with special anchorage.

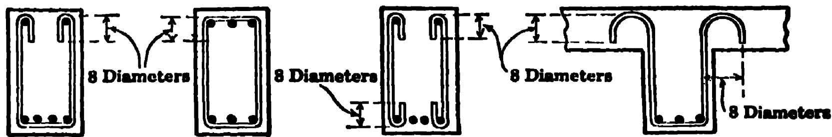
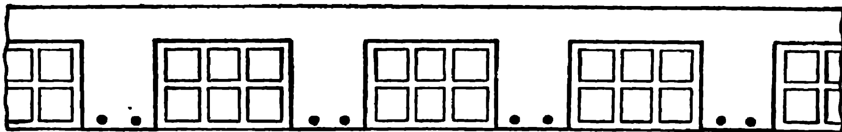


FIG. 12.—Typical methods of anchoring vertical stirrups.


FIG. 13.—Typical reinforced concrete beam-and-tile construction.

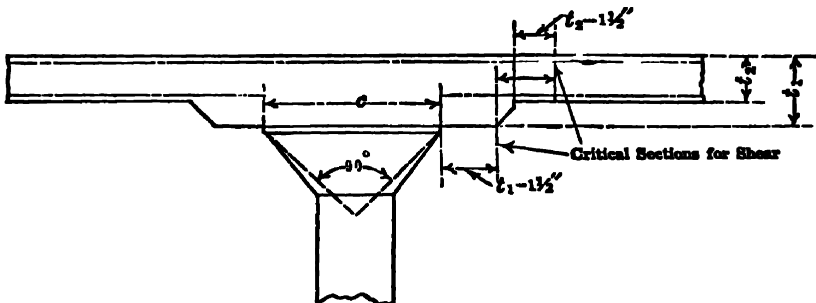


FIG. 14.—Typical column capital and sections of flat slab with dropped panel.

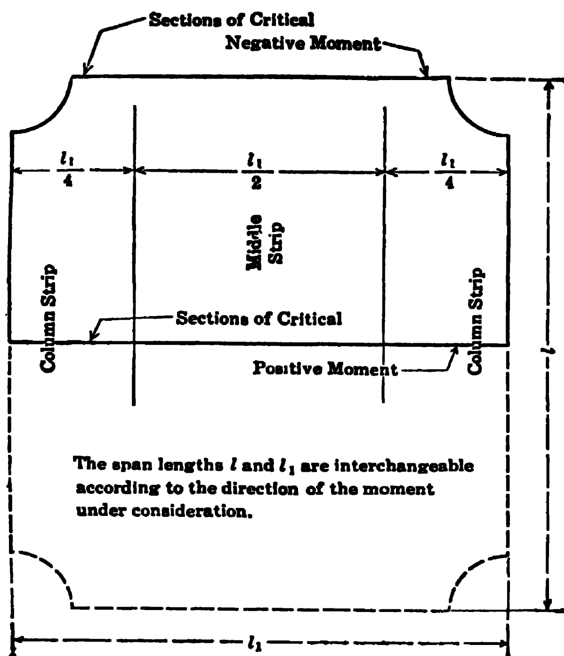


FIG. 15. Principal design sections of a flat slab.

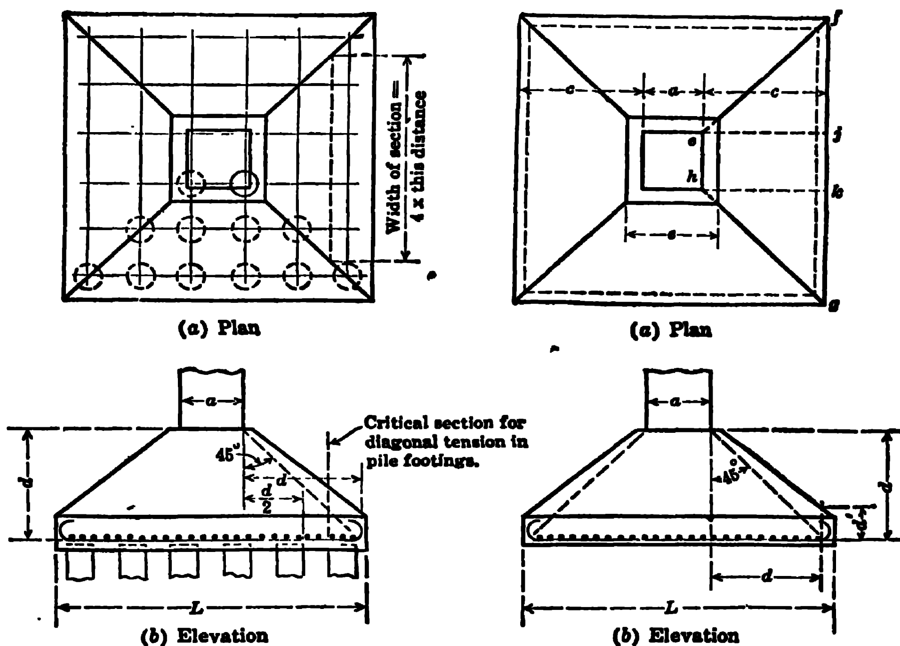


FIG. 16.—Typical sloped reinforced concrete footing on piles.

FIG. 17.—Typical sloped reinforced concrete footing on soil.

APPENDIX K

JOINT CODE

Building Regulations for Reinforced Concrete

Report of Committee E-1 on Reinforced Concrete Building Design and Specifications amended and adopted as a tentative standard at the Twenty-fourth Annual Convention of the American Concrete Institute, Feb. 29, 1928, and adopted as a tentative standard by the Reinforcing Steel Institute at the Fourth Annual Meeting, March 10, 1928.

Introduction.—These regulations have been prepared for use as a part of a general building code. When so used, it is necessary that the following definitions, which give the meaning of certain terms as used in the regulations, become a part of the code. They should appear either in a general chapter in the code relating to definitions or in a chapter by themselves preceding these regulations for the use of reinforced concrete:

DEFINITIONS

Aggregate.—Inert material which is mixed with portland cement and water to produce concrete; in general, aggregate consists of sand, pebbles, gravel, crushed stone, blast-furnace slag, or similar materials.

Anchorage.—The embedment in concrete of a portion of a reinforcement bar, either straight or with hooks, designed to prevent pulling out or slipping of the bar when subjected to stress. (The anchorage of tension reinforcement in beams includes only the embedded length beyond a point of contraflexure or of zero moment.)

Blast-furnace Slag.—The non-metallic product, consisting essentially of silicates and alumino-silicates of lime, which is developed simultaneously with iron in a blast furnace.

Column.—An upright compression member the length of which exceeds three times its least lateral dimension.

Column Capital.—An enlargement of the upper end of a reinforced-concrete column designed and built to act as a unit with the column and flat slab.

Column Strip.—A portion of a flat slab panel one-half panel in width occupying the two quarter-panel areas outside of the middle strip. (See Middle Strip.)

Add also definition as follows:

Combination Column.—A column in which a structural steel section, designed to carry the principal part of the load, is wrapped with wire and encased in concrete of such quality that some additional load may be allowed.

Composite Column.—A column in which a concrete core enclosed by spiral reinforcement and urther reinforced by longitudinal bars encases a structural steel or cast-iron column designed to carry a portion of the load.

Concrete.—A mixture of portland cement, fine aggregate, coarse aggregate and water. (See Mortar.)

Consistency.—A general term used to designate the relative plasticity of freshly mixed concrete or mortar.

Crushed Stone.—Bedded rock or boulders, which have been broken by mechanical means into fragments of varying shapes and sizes.

Dead Load.—The weight of the permanent parts of the structure.

Deformed Bar.—Reinforcement bars with closely spaced shoulders, lugs or projections formed integrally with the bar during rolling so as to firmly engage the surrounding concrete. Wire mesh with welded intersections not farther apart than 12 in. in the direction of the principal reinforcing and with cross-wires not smaller than No. 10 may be rated as a deformed bar.

Diagonal Band.—In a four-way flat-slab system a group of bars covering a width approximately 0.4 the average span, symmetrical with respect to the diagonal running from corner to corner of the panel.

Diagonal Direction.—A direction parallel or approximately parallel to the diagonal of the panel of a flat slab.

Direct Band.—In a four-way flat-slab system, a group of bars covering a width approximately 0.4 l_1, symmetrical with respect to the line of centers of supporting columns.

Dropped Panel.—The structural portion of a flat slab which is thickened throughout an area surrounding the column capital.

Effective Area of Concrete.—The area of a section which lies between the centroid of the tension reinforcement and the compression surface in a beam or slab, and having a width equal to the width of the rectangular beam or slab, or the effective width of the flange of a Tee Beam.

Effective Area of Reinforcement.—The area obtained by multiplying the right cross-sectional area of the metal reinforcement by the cosine of the angle between its direction and that for which the effectiveness of the reinforcement is to be determined.

Flat Slab.—A reinforced-concrete slab generally without beams or girders to transfer the loads to supporting members.

Footing.—A structural unit used to distribute wall or column loads to the foundation materials.

Gravel.—Rounded particles larger than sand grains resulting from the natural disintegration of rocks. (See Sand.)

Laitance.—Extremely fine material of little or no hardness which may collect on the surface of freshly deposited concrete or mortar, resulting from the use of excess mixing water, usually recognised by its relatively light color.

Live Load.—Loads and forces other than the dead load.

Middle Strip.—A portion of a flat-slab panel one-half panel in width, symmetrical with respect to the panel center line and extending through the panel in the direction in which moments are being considered.

Mortar.—A mixture of portland cement, fine aggregate, and water. (See Concrete.)

Negative Bending Moment.—That moment which exists between a support of a slab or beam and the point of inflection on either side of the support.

Negative Reinforcement.—Reinforcement so placed as to take tensile stress due to negative bending moment.

Paneled Ceiling.—A paneled ceiling refers to a flat slab in which approximately that portion of the area enclosed within the intersection of the two middle strips is reduced in thickness.

Panel Length.—The distance in either rectangular direction between centers of two columns of a panel.

Pedestal.—An upright compression member whose height does not exceed three times its least lateral dimension.

Pedestal Footing.—A column footing projecting less than one-half its depth from the faces of the column on all sides and having a depth not more than three times its least width.

Plain Concrete.—Concrete without metal reinforcement.

Portland Cement.—The product obtained by finely pulverizing clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

Positive Bending Moment.—That moment which exists at all other points in beams or slabs except where negative moment exists.

Positive Reinforcement.—Reinforcement so placed as to take tensile stress due to positive bending moment.

Principal Design Section.—The vertical sections in a flat slab on which the moments in the rectangular directions are critical. (See Sec. 1002.)

Ratio of Reinforcement—The ratio of the effective area of the reinforcement cut by a section of a beam or slab to the effective area of the concrete at that section.

Rectangular Direction.—A direction parallel to a side of the panel of a flat slab.

Reinforced Concrete.—Concrete in which metal is embedded in such a manner that the two materials act together in resisting forces.

Sand.—Small grains resulting from the natural disintegration of rocks. (See Gravel.)

Screen.—A metal plate with closely spaced circular perforations. (See Sieve.)

Sieve.—Woven wire cloth with square opening. (See Screen.)

Strut.—A compression member other than a column or pedestal.

Surface Water.—By the term "surface water" is meant all water carried by the aggregate except that held within the aggregate particles themselves by absorption.

Wall Beam.—A reinforced-concrete beam which extends from column to column along the outer edge of a wall panel.

Water-cement Ratio.—By the water-cement ratio is meant the total quantity of water entering the mixture including the surface water carried by the aggregate, expressed in terms of the quantity of cement. The water-cement ratio shall be expressed in U. S. gallons per sack (94 lb.) of cement.

TENTATIVE BUILDING REGULATIONS FOR REINFORCED CONCRETE[1]

CHAPTER 1

GENERAL

101. Scope.—(*a*) These regulations cover the use of reinforced concrete in any structure to be erected under the provisions of the building code of which they form a part. They are intended to supplement the general provisions of the code in order to provide for the proper design and construction of structures of this material. In all matters pertaining to the design and construction where these specific regulations are in conflict with other provisions of the code, these regulations shall govern.

102. Permits and Drawings.—(*a*) Drawings and typical details of all reinforced-concrete construction showing the sizes and position of all structural members, metal reinforcement, and the live-load used in the design shall be filed with the department as a permanent record before a permit to construct such work shall be issued. All calculations made may be required by the department to be submitted with the drawings.

103. Special Systems of Reinforced Concrete.—(*a*) The sponsors of any system of reinforced concrete which has been in successful use, or the adequacy of which has been shown by test, and the design of which is either in conflict with these provisions or not covered by them, shall have the right to present the data on which their design is based to a "Board of Examiners for Special Construction." This Board shall be composed of competent engineers, architects, and builders. The Board shall have the power to investigate the data so submitted and to formulate rulings governing the design and construction of such systems, which ruling shall be of the same force and effect as the provisions of this code. This Board is to be designated as provided elsewhere in the code.

[1] The report of Committee E-1, Reinforced-Concrete Building Design and Specifications, carrying proposed building regulations for reinforced concrete is here published as amended on the floor of the convention, Feb. 29, 1928. As amended this report was adopted as Tentative Building Regulations for Reinforced Concrete (E-1A-28T).

CHAPTER 2

MATERIALS AND TESTS

201. Tests.—(*a*) The tests called for in these regulations when ordered in accordance with the provisions of this chapter by the commissioner of buildings or his authorized representatives shall be arranged for by the owner or his representative. No responsibility for the expense of these tests shall attach to the department of buildings Such tests shall be made in accordance with the standard method of test covering the particular material under consideration. of the American Society for Testing Materials in effect on the date of the adoption of these regulations, except as noted herein.

(*b*) All such tests shall be made by competent persons. The competency of the persons making the tests shall be judged by their training and experience. The commissioner of buildings may disapprove for just cause those whose records show technical incompetency. Copies of the results of all tests shall be kept on file in the office of the commissioner of buildings for a period of two years after the acceptance of the structure. Tests shall be made on any material entering into concrete or reinforced-concrete construction when there is reasonable doubt as to its suitability for the purpose.

(*c*) The commissioner of buildings or his authorized representative shall have the right to require reasonable tests of the concrete from time to time to determine whether the materials and methods in use are such as to produce concrete of the necessary quality. Specimens for such tests shall be taken at the place where concrete is being deposited, and shall be taken, cured, and tested in accordance with the "Standard Method of Making Compression Tests of Concrete" (Serial Designation: C 39-27) of the American Society for Testing Materials.

202. Load Tests.—(*a*) The commissioner of buildings or his authorized representative shall have the right to order the test under load of any portion of a completed structure, when the conditions have been such as to leave reasonable doubt as to the adequacy of the structure to serve the purpose for which it was intended. Such tests shall not be required to be made on any concrete construction which is less than 60 days old.

(*b*) In such tests, the member or portion of the structure under consideration shall be subject to a superimposed load equal to one and one-half times the live load plus one-half of the dead load. This load shall be left in position for a period of 24 hr. before removal. If, during the test, or upon removal of the load, the member or portion of structure shows evident failure, such changes or modifications as are necessary to make the structure adequate for the rated capacity shall be made, or where lawful, a lower rating shall be established. The structure will be considered to have failed to pass the test if within 24 hr. after the removal of the load the slabs or beams do not show a recovery of at least 75 per cent of the maximum deflection shown during the 24 hr. while under load.

203. Inspection.—(*a*) All concrete work shall be inspected by the architect or engineer responsible for its design or by a competent representative responsible to the architect or the engineer. A record shall be kept of such inspection which shall cover the quality and quantity of concrete materials, including water, the mixing and placing of the concrete, and the placing of the reinforcing steel. The inspection record shall also include a complete record of the progress of the work and of the temperatures, when these fall below 40°F., and of the protection given to the concrete while curing. These records shall be available for inspection by the commissioner of buildings at all times during the progress of the work and shall be preserved for 2 years after the acceptance of the structure.

204. Portland Cement.—(*a*) Portland cement shall conform to the "Standard Specifications and Tests for Portland Cement" (Serial Designation: C 9-26) of the American Society for Testing Materials.

205. Concrete Aggregates.—(*a*) Concrete aggregates shall consist of natural sands and gravels, crushed rock, crushed air-cooled blast-furnace slag, or other inert materials having clean, uncoated grains of strong and durable minerals. Aggregates containing soft, friable, thin, flaky, elongated, or laminated particles totaling more than 3 per cent, or containing shale in excess of 1½ per cent, or silt and crusher dust finer than the No. 100 standard sieve in excess of 2 per cent shall not be used. These percentages shall be based on the weight of the combined aggregate as used in the concrete. When all three groups of these deleterious materials are present in the aggregates, the combined amounts shall not exceed 5 per cent by weight of the combined aggregate.

(*b*) Aggregates shall not contain strong alkali or organic material which gives a color darker than the standard color when tested in accordance with the "Standard Method of Test for Organic Impurities in Sands for Concrete" (Serial Designation: C 40-27) of the American Society for Testing Materials.

(*c*) The maximum size of the aggregate shall be not larger than one-fifth of the narrowest dimension between forms of the member for which the concrete is to be used nor larger than three-fourths of the minimum clear spacing between reinforcing bars. By maximum size of aggregate is meant the clear space between the sides of the smallest square opening through which 95 per cent by weight of the material can be passed.

206. Water.—(*a*) Water used in mixing concrete shall be clean, and free from strong acids, alkalis, or organic materials.

207. Metal Reinforcement.—(*a*) Metal reinforcement shall conform to the requirements of the "Standard Specifications for Billet-steel Concrete Reinforcement Bars" of Intermediate Grade[1] (Serial Designation: A 15-14), or for "Rail-steel Concrete Reinforcement Bars" (Serial Designation: A 16-14) of the American Society for Testing Materials. The provision in these specifications for machining deformed bars before testing shall be eliminated.

(*b*) Wire for concrete reinforcement shall conform to the requirements of the "Standard Specifications for

[1] This recommendation is in accordance with "Commercial Standard No. 1 (New Billet-steel Concrete Reinforcing Bars)" of the U. S. Department of Commerce, which establishes the intermediate grade as the single standard for billet-steel reinforcement. Until such time as existing stocks of structural and hard-grade billet-steel reinforcement, meeting the requirements of A. S. T. M. Specification A 15-14 are exhausted, these grades may be used with the unit stresses specified in Sec. 307.

Cold-drawn Steel Wire for Concrete Reinforcement" (Serial Designation: A 82-27) of the American Society for Testing Materials.

(c) Structural steel shall conform to the requirements of the "Standard Specifications for Structural Steel for Buildings" (Serial Designation: A 9-24) of the American Society for Testing Materials.

(d) Cast-iron sections for composite or combination columns shall conform to "Standard Specifications for Cast-Iron Pipe and Special Castings" (Serial Designation: A 44-04) of the American Society for Testing Materials.

208 **Storage of Materials.**—(a) Cement and aggregates shall be stored at the work in a manner to prevent deterioration or the intrusion of foreign matter. Any material which has deteriorated or has been damaged shall be immediately and completely removed from the work.

CHAPTER 3

CONCRETE QUALITY AND WORKING STRESSES

301. **Concrete Quality.**—(a) The working stresses for the design of reinforced-concrete structures shall be based upon the minimum ultimate 28-day strength of the concrete to be used in the structure in accordance with the values given in Sec. 306. All plans for which all parts of the structure were designed. The strength of concrete submitted for approval or used on the work shall clearly show the strength of concrete shall be fixed in terms of the water-cement ratio in accordance with one of the following methods:

(1) By established results for average materials, as provided in Sec. 302.

(2) By specific test of materials for the structure, as provided in Sec. 303.

(b) By the water-cement ratio is meant the total quantity of water entering the mixture including the surface water carried by the aggregate, expressed in terms of the quantity of cement. The water-cement ratio shall be expressed in U. S. gal. per sack (94 lb.) of cement.

302. **Water-cement Ratio for Average Materials.**—(a) Where no preliminary tests of the materials to be used are made, the water-cement ratios shall not exceed the values in the following table. The mixes shown in the table are approximate only, and may require adjustment to give proper workability.

ASSUMED STRENGTH OF CONCRETE MIXTURES

Water-cement ratio U. S. gallons per 94-pound sack of cement	Approximate mix volume of portland cement to sum of separate volumes of fine and coarse aggregate as measured dry plastic concrete	Assumed compressive strength at 28 days in pounds per square inch
8¼	1:7	1500
7½	1:6	2000
6¾	1:5¼	2500
6	1:4½	3000
	Moderately wet concrete	
8¼	1:6½	1500
7½	1:5½	2000
6¾	1:4¾	2500
6	1:4	3000

NOTE: In interpreting this table, surface water contained in the aggregate must be included as part of the mixing water in computing the water-cement ratio.

(b) During the progress of the work, a reasonable number of compression tests shall be made as may be required by the commissioner of buildings, but at least one specimen shall be tested for each 100 cu. yd. of concrete being placed. The tests shall be made in accordance with provisions of Sec. 304. Should the average 28-day strength fall below the minimum ultimate strength called for on the plans, the commissioner of buildings shall have the right to require a load test under the provisions of Sec. 202.

303. **Water-cement Ratio by Tests of Materials.**—(a) Where the water-cement ratios for the various strengths of concrete are to be established by tests, these tests shall be made in advance of the beginning of operations using the materials proposed and consistencies suitable for the work and in accordance with the "Standard Method of Making Compression Tests of Concrete" (Serial Designation C 39-27) of the American Society for Testing Materials, including the provisions for curing in a moist room at 70°F. and testing wet. A curve representing the relation between the average 28-day strength of the concrete and water-cement ratio shall be established for a range of values

including all of the strengths called for in the plans. The tests shall include at least four different water-cement ratios and at least four specimens for each water-cement ratio. The water-cement ratio to be used in the structure shall be that corresponding to a point on the curve established by these tests representing a strength of concrete 15 per cent higher than the minimum ultimate strength called for on the plans and satisfactory evidence shall be submitted to show that these water-cement ratios are not exceeded. No substitution shall be made in the materials being used on the work without additional tests in accordance, herewith, to show the new water-cement ratios to be used.

(*b*) During the progress of the work, a reasonable number of additional 28-day compression tests may be required by the Commissioner of Buildings, but at least one specimen shall be tested for each 50 cu. yd. of concrete of any one strength, and not less than two specimens of each strength of concrete for any one day's operation. Such tests shall be made in accordance with the provisions of Sec. 304. Should the average strengths of the control cylinders shown by these tests for any portion of the structure fall below the minimum ultimate 28-day strengths called for on the plans, the commissioner of buildings shall have the right to order a change in the mix or the water-cement ratios for the remaining portion of the structure and to require load tests as specified in Sec. 202 on the portions of the building affected. Should the average strengths shown by the cylinders cured on the job and tested subsequent to 28 days fall below the required strength, the commissioner of buildings shall have the right to require conditions of temperature and moisture necessary to secure the required strength.

304. Field Tests of Concrete.—(*a*) Field tests of concrete, when required, shall be made in accordance with the "Standard Method of Making Compression Tests of Concrete" (Serial Designation C 39-27) of the American Society for Testing Materials with the following exceptions:

(1) Two sets of samples of concrete for test specimens shall be taken as the concrete is being delivered at the point of deposit, care being taken to obtain a sample representative of the entire batch.

(2) One set designated as control cylinders shall be placed under moist curing conditions at approximately 70°F. within 24 hr. after molding and maintained therein until tested.

(3) The second set, designated as job cylinders, shall be kept as near to the point of pling as possible and yet receive the same protection from the elements as is given to the por ions of the structure being placed. Specimens shall be kept from injury while on the work. They shall be sent to the laboratory not more than 7 days prior to the time of test and while in the laboratory shall be kept in the ordinary air at a temperature of approximately 70°F.

(*b*) All specimens and tests shall be made by a properly qualified person or testing laboratory, who shall furnish the commissioner of buildings with a report, certified in the presence of a notary public, showing the results of tests and stating that they were made in accordance with the provisions of this code.

305. Concrete Proportions and Consistency.—(*a*) The proportions of aggregates to cement for concrete of any water-cement ratio shall be such as to produce concrete that will work readily into the corners and angles of the form and around the reinforcement without excessive puddling or spading and without permitting the materials to segregate or free water to collect on the surface. The combined aggregate shall be of such composition of sizes that when separated by the No. 4 standard sieve, the weight retained on the sieve shall not be less than one-third nor more than two-thirds of the total nor shall the amount of coarse material be such as to prod ce harshness in placing or honeycombing in the structure. When forms are removed, the faces and corners of th members shall show smooth and sound throughout.

(*b*) The methods of measuring concrete materials shall be such that the proportion of water to cement can be accurately controlled during the progress of the work and easily checked at any time by the commissioner of buildings or his authorised representative.

306. Allowable Unit Stresses in Concrete.—(*a*) The unit stresses in pounds per square inch on the concrete to be used in the design shall not exceed the following values, where f'_c equals the minimum ultimate strength at 28 days.

DESCRIPTION	Allowable unit stresses			
	For any strength of concrete as fixed by test in accordance with Sec. 303 $n = \frac{30000}{f'_c}$	When strength of concrete is fixed by the water-cement ratio in accordance with Sec. 302		
		f'_c = 2000 lb. n = 15	f'_c = 2500 lb. n = 12	f'_c = 3000 lb. n = 10
Flexure: f_c.				
Extreme fiber stress in compression (f_c)	$0.40f'_c$	800	1000	1200
Extreme fiber stress in compression adjacent to supports of continuous or fixed beams or of rigid frames (f_c)	$0.45f'_c$	900	1125	1350
Shear: v.				
Beams with no web reinforcement and without special anchorage of longitudinal steel (v_c)	$0.02f'_c$	40	50	60
Beams with no web reinforcement, but with special anchorage of longitudinal steel (v_c)	$0.03f'_c$	60	75	90
Beams with properly designed web reinforcement, but without special anchorage of longitudinal steel (v)	$0.06f'_c$	120	150	180
Beams with properly designed web reinforcement and with special anchorage of longitudinal steel (v)	$0.09f'_c$	180	225	270
For conditions determining the use of greater shear values see Sec. 903(*e*).				
Flat slabs at distance d from edge of column cap or drop panel (v_c)	$0.03f'_c$	60	75	90
Footings where longitudinal bars have no special anchorage (v_c)	$0.02f'_c$	40	50	60
Footings where longitudinal bars have special anchorage (v_c)	$0.03f'_c$	60	75	90
Bond: u.				
In beams and slabs and one-way footings:				
Plain bars (u)	$0.04f'_c$	80	100	120
Deformed bars (u)	$0.05f'_c$	100	125	150
In two-way footings:				
Plain bars (u)	$0.03f'_c$	60	75	90
Deformed bars (u)	$0.0375f'_c$	75	94	112
(Where special anchorage is provided (see Sec. 903), double these values in bond may be used)				
Bearing: f_c.				
Where a concrete member has an area at least twice the area in bearing (f_c)	$0.25f'_c$	500	625	750
Axial Compression: f_c.				
In columns with lateral ties (f_c)	$0.225f'_c$	450	563	675
In columns with continuous spirals enclosing a circular core:[1]				
Ratio of longitudinal reinforcement p = 0.01	$300 + 0.14f'_c$	580	650	720
0.02	$300 + 0.18f'_c$	660	750	840
0.03	$300 + 0.22f'_c$	740	850	960
0.04	$300 + 0.26f'_c$	820	950	1080
0.05	$300 + 0.30f'_c$	900	1050	1200
0.06	$300 + 0.34f'_c$	980	1150	1320
(Spiral reinforcement not to be less than ¼ the longitudinal.)				

[1] Unit stress in spirally reinforced columns = $[300 + (0.10 + 4p)f'_c]$.

307. **Allowable Unit Stresses in Reinforcement.**—(*a*) The following unit stresses in reinforcing steel shall not be exceeded:

Tension:

Intermediate grade billet steel[1]	(f_s)	= 20,000 lb. per sq. in.
Rail steel bars	(f_s)	= 20,000 lb. per sq. in.
Web reinforcement	(f_v)	= 16,000 lb. per sq. in.
Structural steel shapes	(f_s)	= 18,000 lb. per sq. in.
Other steel reinforcement 50 per cent of the yield point stress, but not to exceed	(f_s)	= 20,000 lb. per sq. in.

Compression:

Bars	nf_c
Structural steel section in composite columns	15,000 lb. per sq. in.
Cast Iron section in composite columns	9,000 lb. per sq. in.

See Sec. 1106 for stresses in structural steel and cast iron not encased in concrete.

Structural steel section in combination column, see Sec. 1107.

CHAPTER 4

MIXING AND PLACING CONCRETE

401. **Removal of Water from Excavation.**—(*a*) Water shall be removed from excavations before concrete is deposited, unless otherwise directed by the commissioner of buildings. Any flow of water into the excavation shall be diverted through proper side drains to a sump, or be removed by other approved methods which will avoid washing the freshly deposited concrete. Water vent pipes and drains shall be filled by grouting or otherwise, after the concrete has thoroughly hardened.

402. **Cleaning Forms and Equipment.**—(*a*) Before placing concrete, all equipment for mixing and transporting the concrete shall be cleaned, all debris and ice shall be removed from the places to be occupied by the concrete, forms shall be thoroughly wetted (except in freezing weather) or oiled, and clay or cement tile that will be in contact with concrete shall be well drenched (except in freezing weather). Reinforcement shall be thoroughly cleaned of ice or other coatings.

403. **Inspection.**—(*a*) Concrete shall not be placed until the forms and reinforcement have been inspected by the architect or engineer responsible for the design or his authorized representative.

Structural grade	(f_s)	= 18,000 lb. per sq. in.
Hard grade	(f_s)	= 20,000 lb. per sq. in.

404. **Mixing.**—(*a*) The concrete shall be mixed until there is a uniform distribution of the materials and the mass is uniform in color and homogeneous. The mixer shall be of such type as to insure the maintaining of the correct proportions of the ingredients. The mixing shall continue for at least one minute after all the ingredients are in the mixer.

405. **Transporting.**—(*a*) Concrete shall be handled from the mixer to the place of final deposit as rapidly as practicable by methods which will prevent the separation or loss of the ingredients. It shall be deposited as nearly as practicable in its final position to avoid rehandling or flowing. Under no circumstances shall concrete that has partially hardened be deposited in the work.

(*b*) When concrete is conveyed by chuting, the plant shall be of such size and design as to insure a practically continuous flow in the chute. The slope of the chute shall be such as to allow the concrete to flow without separation of the ingredients. The delivery end of the chute shall be as close as possible to the point of deposit. When the operation is intermittent, the spout shall discharge into a hopper. The chute shall be thoroughly flushed with water before and after each run; the water used for this purpose shall be discharged outside the forms.

406. **Placing.**—(*a*) When concreting is once started, it shall be carried on as a continuous operation until the placing of the section or panel is completed. Where construction joints are necessary, they shall be made in accordance with Sec. 507.

(*b*) Concrete shall be thoroughly compacted by puddling with suitable tools during the operation of placing, and thoroughly worked around the reinforcement, around embedded fixtures, and into the corners of the forms.

(*c*) Where conditions make puddling difficult, or where the reinforcement is congested, batches of mortar containing the same proportion of cement to sand used in the concrete, shall first be deposited in the forms and the operation of filling with the regularly specified mix be carried on at such a rate that the mix is at all times plastic and flows readily into the spaces between the bars.

(*d*) A record shall be kept on the work of the time and date of placing the concrete in each portion of the structure. Such record shall be kept until the completion of the structure and shall be open to the inspection of the commissioner of buildings.

407. **Curing.**—(*a*) Exposed surfaces of concrete shall be kept moist for a period of at least 7 days after being deposited. In hot weather, exposed concrete shall be thoroughly wetted twice daily during the first week.

408. **Depositing in Cold Weather.**—(*a*) When depositing concrete at freezing or near freezing temperatures, the concrete shall have a temperature of at least 50°F., but not more than 120°F. The concrete shall be maintained at a temperature of at least 50°F. for not less than 72 hr. after placing or until the concrete has thoroughly hardened. When necessary, concrete materials shall be heated before mixing. Dependence shall not be placed on salt or other

[1] Until existing stocks of structural and hard grades of billet-steel reinforcement are exhausted, these grades, if conforming to the provision of Sec. 207, may be used with the following unit stresses:

chemicals for the prevention of freezing. No frozen materials or materials containing ice shall be used. Manure shall not be applied directly to concrete when used for protection.

CHAPTER 5

FORMS AND DETAILS OF CONSTRUCTION

501. **Design of Forms.**—(*a*) Forms shall conform to the shape, lines, and dimensions of the member as called for on the plans. They shall be substantial and sufficiently tight to prevent leakage of mortar; they shall be properly braced or tied together so as to maintain position and shape and insure safety to workmen and passersby. Temporary openings shall be provided where necessary, to facilitate cleaning and inspection immediately before depositing concrete.

502. **Removal of Forms.**—(*a*) The removal of forms shall be carried out in such a manner as to insure the complete safety of the structure. Where the structure as a whole is supported on shores, removable floor forms, beams and girder sides, column and similar vertical forms may be removed within 24 hr., providing the concrete has hardened sufficiently that it is not injured. In no case shall the supporting forms be disturbed until the concrete has hardened sufficiently to permit their removal with safety. Shoring shall not be removed until the member has acquired sufficient strength to support safely its weight and the load upon it.

503. **Cleaning and Bending Reinforcement.**—(*a*) Metal reinforcement, before being placed, shall be free from rust scale or other coatings that will destroy or reduce the bond. Reinforcement shall be formed to the dimensions indicated on the plans. Cold bends shall be made around a pin having a diameter of four or more times the least dimension of the bar.

(*b*) Metal reinforcement shall not be bent or straightened in a manner that will injure the material. Bars with kinks or bends not shown on the plans shall not be used. Heating of reinforcement for bending will not be permitted.

504. **Placing Reinforcement.**—(*a*) Metal reinforcement shall be accurately placed and secured, and shall be supported by concrete or metal chairs or spacers, or metal hangers. The minimum center to center distance between parallel bars shall be two and one-half times the diameter for round bars or three times the side dimension for square bars; if the ends of bars are anchored as specified in Sec. 903, the center to center spacing may be made equal to two diameters for round bars or to two and one-half times the side dimension for square bars, but in no case shall the clear spacing between bars be less than 1 in., nor less than one and one-third times the maximum size of the coarse aggregate. Bars at the upper face of any member shall be embedded a clear distance of not less than one diameter, nor less than 1 in.

505. **Splices and Offsets in Reinforcement.**—(*a*) In slabs, beams, and girders, splices of reinforcement shall not be made at points of maximum stress without the approval of the commissioner of buildings. Splices, where permitted, shall provide sufficient lap to transfer the stress between bars by bond and shear. In such splices, the bars shall be spaced at the minimum distance specified in Sec. 504.

(*b*) Splices in column bars shall provide a lap of twenty-four diameters for deformed bars and thirty diameters for plain bars.

(*c*) Where changes in the cross-section of a column occur, the longitudinal bar shall be sloped for the full length of the column or offset in a region where lateral support is afforded. Where offset, the slope of the inclined portion from the axis of the column shall not be more than 1 in 6.

506. **Protective Covering of Concrete.**—(*a*) At those surfaces of footings and other principal structural members in which the concrete is deposited directly against the ground, metal reinforcement shall have a minimum covering of 3 in. of concrete. At other surfaces of concrete exposed to the ground or weather, metal reinforcement shall be protected by not less than 2 in. of concrete.

(*b*) In fire-resistive construction, metal reinforcement shall be protected by not less than 1 in. of concrete in slabs and walls, and not less than 1½ in. in beams, girders, and columns, provided coarse aggregate is used, which is free from disruptive action under high temperatures, as, for example, limestone or trap rock; when impracticable to obtain aggregate of this grade, the protective covering shall be ½ in. thicker and shall be reinforced with metal mesh having openings not exceeding 3 in. placed 1 in. from the finished surface. In similar structures where the fire hazard is limited, the metal reinforcement shall not be placed nearer the exposed surface than ¾ in. in slabs and walls, or 1 in. in beams, girders, and columns.

(*c*) Cement or gypsum plaster, ¾ in. or more in thickness (on metal lath weighing not less than 2½ lb. per sq. yd. when used vertically, nor less than 3 lb. per sq. yd. when used horizontally) may be substituted for a part of the protective covering of concrete, provided that only two-thirds of the thickness of the plaster be considered effective and the concrete protection shall in no case be reduced to less than ¾ in.

(*d*) Exposed reinforcement bars intended for bonding with future extensions shall be protected from corrosion.

507. **Construction Joints.**—(*a*) Joints not indicated on the plans shall be so made and located as to least impair the strength of the structure. Where a horizontal joint is to be made, any excess water and laitance shall be removed from the surface after concrete is deposited. Before depositing of concrete is resumed, the hardened surface shall be cleaned and roughened and all weak concrete removed.

(*b*) At least 2 hr. must elapse after depositing concrete in the columns or walls before depositing in beams, girders, or slabs supported thereon. Beams, girders, brackets, column capitals, and haunches shall be considered as part of the floor system and shall be placed monolithically therewith.

(*c*) Construction joints in floors shall be located near the middle of spans of slabs, beams, or girders, unless a beam intersects a girder at this point, in which case the joints in the girders shall be offset a distance equal to twice the width of the beam. In this last case provision shall be made for shear by use of inclined reinforcement.

CHAPTER 6

DESIGN—GENERAL CONSIDERATIONS

601. Assumptions.—(*a*) The design of reinforced-concrete members under these specifications shall be made with reference to working stresses and safe loads. The accepted theory of flexure as applied to reinforced concrete shall be applied to all members resisting bending involving the following assumptions:

(1) The steel takes all tensile stress,

(2) The ratio n of the modulus of elasticity of the steel to that of the concrete shall be taken as follows (applies also for compression members):

$$n = \frac{E_s}{1{,}000f'_c} = \frac{30{,}000}{f'_c}$$

602. Notation.—(*a*) The symbols and notation used in these regulations are defined as follows:

a = width of face of column or pedestal;
α = angle between inclined web bars and axis of beam;
A = total area of top of pedestal, pier, or footing;
A' = loaded area of pedestal, pier, or footing at the column base;
A_c = area of core of spirally-hooped column measured to the outside diameter of the spiral;
A_g = gross area of tied columns with lateral ties;
A_s = effective cross-sectional area of metal reinforcement in tension in beams or compression in columns; and the effective cross-sectional area of metal reinforcement which crosses any of the principal design sections of a flat slab and which meets the requirements of Sec. 1006, 1008, 1009, and 1010.
A_v = total area of web reinforcement in tension within a distance of s (measured perpendicular to the direction of the web reinforcement bar), or the total area of all bars bent up in any one plane;
b = width of rectangular beam or width of flange of T-beam;
b' = thickness of web in beams of I or T sections;
b_1 = dimension of the dropped panel of a flat slab in the direction parallel to l_1;
c = diameter in feet of column capital of a flat slab at the underside of the slab, or dropped panel. No portion of the column capital shall be considered for structural purposes which lies outside of the largest 90-deg. cone that can be included within the outlines of the column capital;
c = projection of footing from face of column or pedestal;
d = depth from compression surface of beam or slab to center of longitudinal tensile reinforcement;
E_c = modulus of elasticity of concrete in compression;
E_s = modulus of elasticity of steel in tension or compression = 30,000,000 lb. per sq. in.;
f_c = compressive unit stress in extreme fiber of concrete in flexure or axial compression in concrete in columns;
f'_c = ultimate compressive strength of concrete at age of 28 days;
f_r = compressive unit stress in metal core;
f_s = tensile unit stress in longitudinal reinforcement;
f_v = tensile unit stress in web reinforcement;
h = unsupported length of column;
I = moment of inertia of a section about the neutral axis for bending;
l = span length of beam or slab (generally distance from center to center of supports; for special cases see Secs. 702 and 1005;
l = span length of flat-slab panel (usually expressed in feet) center to center of columns, in the direction in which moments are considered (see Sec. 1003);
l_1 = span length of flat slab, center to center of columns, perpendicular to the rectangular direction in which moments are considered;
M = bending moment or moment of resistance in general;
M_o = sum of positive and negative bending moments at the principal design sections of a panel or a flat slab (see Sec. 1003);
n = E_s/E_c = ratio of modulus of elasticity of steel to that of concrete;
Σ_o = sum of perimeters of bars in one set;
p = ratio of effective area of tensile reinforcement to effective area of concrete in beams = A_s/bd; and the ratio of effective area of longitudinal reinforcement to the area of the concrete core in columns;
p_a = permissible unit stress on pedestal, pier, or footing when the full area is loaded;
P = total safe axial load on column whose length does not exceed 11 times its least cross-sectional dimension;
P' = total safe axial load on long column;
r_a = permissible unit working stress in concrete over the loaded area of a pedestal, pier, or footing;
R = least radius of gyration of a section;
s = spacing of stirrups measured perpendicular to the direction of the stirrup;
t = thickness of flange of T-beam;
t_1 = thickness of flat slab without dropped panels; or the thickness of flat slabs, including dropped panels where one is used;
t_2 = thickness of flat slab with dropped panels at points away from the dropped panel;
u = bond stress per unit of area of surface of bar;
v = shearing unit stress;
v_c = unit shearing stress permitted on the concrete of the web; the value depending on the anchorage of the longitudinal reinforcement;

V = total shear;
V' = excess of the total shear over that permitted on the concrete;
w = uniformly distributed load per unit of length of beam or slab;
w = upward reaction per unit of area of base of footing;
w' = uniformly distributed dead and live load per unit of area of a floor or roof (in flat slabs usually expressed in pounds per square foot);
W = total dead and live load uniformly distributed over a single panel area (in flat slabs usually expressed in pounds and includes the dead weight of any raised or depressed portions).

603. **Design Loads.**—(*a*) The provisions for design herein specified are based on the assumption that all structures shall be designed for all dead and live loads coming upon them, the live loads to be in accordance with the general requirements of the building code of which this forms a part, with such reductions for girders and lower story columns as are permitted therein.

604. **Wind Loads.**—(*a*) Provisions shall be made for wind loads in accordance with the general provisions of the code of which this forms a part. In designing the members to resist wind loads, the allowable unit stresses for dead and live loads and wind loads may be increased to 150 per cent of the allowable values specified in Secs. 306 and 307, but the section shall not be less than that required if the wind load be neglected.

CHAPTER 7

FLEXURAL COMPUTATIONS AND MOMENT COEFFICIENTS

701. **Formulas for Flexure.**—(*a*) Computations of flexural resistance of reinforced-concrete beams and slabs shall be based on the assumptions of Sec. 601. The customary formulas or their equivalent shall be used.

702. **Span Length.**—(*a*) The span length of freely supported beams and slabs shall be the clear span plus the depth of beam or slab, but shall not exceed the distance between centers of the supports.

(*b*) The span length for continuous or restrained beams built to act integrally with supports shall be the clear distance between faces of supports.

(*c*) For continuous or restrained beams having brackets built to act integrally with both beam and support and of a width not less than the width of the beam and making an angle of 45 deg. or more with the horizontal, the span shall be measured from the section where the combined depth of the beam and bracket is at least one-third more than the depth of the beam. No portion of such a bracket shall be considered as adding to the effective depth of the beam. Brackets making an angle of less than 45 deg. with the horizontal may be considered as increasing the effective depth of the beam, but not as decreasing the span length.

(*d*) Maximum negative moments are to be considered as existing at the ends of the span, as defined above.

703. **Depth of Beam or Slab.**—(*a*) The depth of the beam or slab shall be taken as the distance from the centroid of the tensile reinforcement to the top surface of the structural slab. Any floor finish not placed monolithic with the floor slab shall not be included as a part of the structural member. When the finish is placed monolithic with the structural slab in buildings of the warehouse or industrial class where the finish is subjected to unusual wear from trucking or other causes, there shall be placed an additional depth of ½ in. over that used in the design of the member.

704. **Point of Inflection.**—(*a*) For the purpose of these regulations, the point of inflection in beams and slabs of equal spans symmetrically loaded shall be assumed to be located at the fifth point of the span as defined in Sec. 702.

705. **Distance between Lateral Supports.**—(*a*) The clear distance between lateral supports of a beam shall not exceed 32 times the least width of compression flange.

706. **Requirements for T-beams.**—(*a*) In T-beam construction the slab shall be built integrally with the beam. The effective flange width to be used in the design of symmetrical T-beams shall not exceed one-fourth of the span length of the beam, and its overhanging width on either side of the web shall not exceed eight times the thickness of the slab nor one-half the clear distance to the next beam.

(*b*) For beams having a flange on one side only, the effective overhanging flange width shall not exceed one-twelfth of the span length of the beam, nor six times the thickness of the slab, nor one-half the clear distance to the next beam.

(*c*) Where the principal reinforcement in a slab which is considered as the flange of a T-beam (not a rib in ribbed floors) is parallel to the beam, transverse reinforcement shall be provided in the top of the slab. This reinforcement shall be designed to carry the load on the portion of the slab assumed as the flange of the T-beam. The spacing of the bars shall not exceed five times the thickness of the flange, or in any case 18 in.

(*d*) Provision shall be made for the compressive stress at the support in continuous T-beam construction, care being taken that the provisions of Sec. 504, relating to the spacing of bars, and 406(*c*), relating to the placing of concrete shall be fully met. In no case shall the area of steel in compression at any cross-section adjacent to the support exceed 2 per cent of the cross-sectional area of the stem of the beam in that section.

(*e*) The overhanging portion of the flange of the beam shall not be considered as effective in computing the shear and diagonal tension resistance of T-beams.

(*f*) Isolated beams in which the T-form is used only for purpose of providing additional compression area, shall have a flange thickness not less than one-half the width of the web and a total flange width not more than four times the web thickness.

707. **Ribbed Floor Construction.**—(*a*) Ribbed floor construction includes floor systems of ribs and slabs placed monolithically in which the ribs are not farther apart than 36 in. face to face. The ribs shall be straight, not less than 4 in. wide, nor of a depth more than three times the width.

(*b*) Where removable forms or fillers not complying with (*c*) are used the thickness of the concrete slab shall not be less than one-twelfth of the clear distance between ribs and in no case less than 2 in.

(c) When burned clay or cement tile are used and concrete is placed on the top of such tile, it shall not be less than $1\frac{1}{2}$ in. in thickness, nor less than one-twelfth of the clear distance between ribs. When the tile are so placed that the joints in alternate rows are staggered, the webs of the tile in contact with the ribs may be included in calculations involving shear or negative bending moment. No other portion of the tile may be included in design calculations.

(d) Where the floor is subject to impact from moving loads, or to wear, the slab thicknesses shall be increased $\frac{1}{2}$ in. If a floor or covering $\frac{1}{2}$ in. or more in thickness, not included in the structural slab, is used for a wearing surface, no increase need be made.

(e) Where the slab contains conduits or pipes, the thickness shall not be less than 1 in. plus the total overall depth of such conduits or pipes at any point. Such conduits or pipes shall be so located as not to reduce the strength of the construction.

(f) Shrinkage reinforcement in the slab must be provided as required in Sec. 712.

708. Moment Coefficients for Freely Supported or Slightly Restrained Continuous Beams or Slabs of Approximately Equal Span; Uniform Load.—(a) Beams and slabs of approximately equal spans freely supported or built to act integrally with beams, girders, or other slightly restraining support, or beams and slabs built into brick or masonry walls in a manner which develops only partial end restraint, and carrying uniformly distributed loads shall be designed for the following moments at critical sections:

(1) Beams and slabs of one span,

Positive moment near center,

$$M = \frac{wl^2}{8} \tag{1}$$

(2) Beams and slabs continuous for two spans only,

Positive moment near center,

$$M = \frac{wl^2}{10} \tag{2}$$

Negative moment over interior support,

$$M = \frac{wl^2}{8} \tag{3}$$

(3) Beams and slabs continuous for more than two spans,

Positive moment near center and negative moment at supp[illegible] of in[illegible] spans,

$$M = \frac{wl^2}{12} \tag{4}$$

Positive moment near centers of end spans and negative moment at first interior support,

$$M = \frac{wl^2}{10} \tag{5}$$

(4) Negative moment at end supports for cases (1), (2), and (3) of this section,

$$M = \text{not less than } \frac{wl^2}{24} \tag{6}$$

709. Moment Coefficients for Fully Restrained Continuous Beams or Slabs of Approximately Equal Span; Uniform Load.—(a) Beams and slabs of approximately equal spans built to act integrally with columns, walls, or other restraining supports and assumed to carry uniformly distributed loads, shall (except as provided in Sec. 708) be designed for the following moments at critical sections:

(1) Interior spans;

Negative moment at interior supports except the first,

$$M = \frac{wl^2}{12} \tag{7}$$

Positive mo[illegible]ent near [illegible]nters of interior spans,

$$M = \frac{wl^2}{16} \quad (\,$$

(2) End spans of continuous beams or slabs, and beams or slabs of one span;

Where I/l is less than twice the sum of the values of I/h for the exterior columns above and belo which are built into the beams:

Positive moment near center of span and negative moment at first interior supports,

$$M = \frac{wl^2}{12} \tag{9}$$

Negative moment at exterior supports,

$$M = \frac{wl^2}{12} \tag{10}$$

Where I/l is equal to or greater than twice the sum of the values of I/h for the exterior column abov and below which are built into the beams:

Positive moment near center of span and negative moment at first interior support,

$$M = \frac{wl^2}{10} \tag{11}$$

Negative moment at exterior support,

$$M \quad wl^2 \tag{12}$$

(b) In this section, I represents the moment of inertia which, for those calculations, shall be computed on the assumption that the member is homogeneous, neglecting the reinforcement, but including that portion of the concrete section outside of the reinforcement which is ordinarily considered as fireproofing. l and h are the span length and column height, respectively, as defined in Secs. 702 and 1102.

710. Moment Coefficients for Continuous Beams or Slabs of Unequal Span or with Non-uniform Loads.—(a) Continuous beams with substantially unequal spans, or with other than uniformly distributed loading, whether freely supported or restrained, shall be designed for the maximum moments resulting from the most severe probable combination of loading and restraint. Provision shall be made where necessary for negative moment near the center of short spans which are adjacent to long spans, and for the negative moment at the end supports, if restrained.

711. Compression Steel in Flexural Members.—(a) Where it is necessary to introduce steel in compression in girders, beams, or slabs, such steel shall be thoroughly anchored by ties or stirrups not less than ¼ in. in size which shall be spaced not more than 8 in. apart over the distance where the compression steel is required.

712. Shrinkage and Temperature Reinforcement.—(a) Reinforcement for shrinkage and temperature stresses normal to the principal reinforcement shall be provided in floor and roof slabs where the principal reinforcement extends in one direction only. Such reinforcement shall provide for the following minimum ratios of reinforcement area to concrete area, but in no case shall such reinforcing bars be placed farther apart than five times the slab thickness nor more than 18 in.:

Floor slabs where plain bars are used	0.0025
Floor slabs where deformed bars are used	0.002
Floor slabs where wire fabric is used, having welded intersections not farther apart in the direction of stress than 12 in.	0.0018
Roof slabs where plain bars are used	0.003
Roof slabs where deformed bars are used	0.0025
Roof slabs where wire fabric is used, having welded intersections not farther apart in the direction of stress than 12 in.	0.0022

713.[1] Floors Reinforced in Two Directions.—(a) Concrete floors supported on four sides by beams, girders, or walls, and reinforced in two directions, shall be designed as follows, using moment coefficients given in Secs. 708, 709, and 710 as required, except as indicated under (e).

(b) If the length of the slab exceeds one and one-half times its width, the entire load shall be carried in the short direction.

(c) In case of square panels and uniformly distributed load, one-half the live and dead load may be assumed as being resisted by each cross-band.

(d) In rectangular panels of length L and breadth B, the portion of the load which shall be assumed as being supported by the slab in the short direction shall be equal to $\left(\frac{L}{B} - \frac{1}{2}\right)$ times the total load. The remainder of the load shall be assumed as being supported by the slab in the long direction. The reinforcement in the long direction shall in no case be less than that specified in Sec. 712 for shrinkage and temperature reinforcement.

(e) In placing the reinforcement account may be taken of the facts that the moment is less in the portions of the band which are adjacent and parallel to the supporting beams. In the one-quarter width of band parallel and adjacent to the beams, the computed moment may be reduced 50 per cent.

(f) Beams supporting such slabs shall be assumed to take the portion of the load as determined in (b), (c), or (d) without advantage of any reduction in live load permitted in other sections of this code. The total load for each beam shall be assumed as uniformly distributed.

714. Maximum Spacing of Principal Slab Reinforcement.—(a) In slabs other than ribbed floor construction or flat slabs, the principal reinforcement shall not be spaced farther apart than three times the slab thickness, nor shall the ratio of reinforcement be less than specified in Sec. 712 (a).

CHAPTER 8

SHEAR AND DIAGONAL TENSION

801. Shearing Unit Stress.—(a) The shearing unit stress (v) in reinforced-concrete beams shall be computed by formula (14):

$$v = \frac{8V}{7bd} \qquad (14)$$

When the value of the shearing unit stress computed by formula (14) exceeds the unit shearing stress (v_c) permitted on the concrete of the web (sec 306 a), web reinforcement shall be provided to carry the excess.

(b) For beams of I or T section b' shall be substituted for b in formula (14).

(c) In tile and joist construction, b may be taken as a width equal to the thickness of the concrete web plus the thickness of the vertical webs of the concrete or clay tile in contact with the joist as in Sec. 707c.

802. Types of Web Reinforcement.—(a) Web reinforcement may consist of:

(1) Vertical stirrups or web-reinforcing bars;

(2) Inclined stirrups or web-reinforcing bars forming an angle of 30 deg. or more with the axis of the beam.

(3) Longitudinal bars bent up at an angle of 15 deg. or more with the axis of the beam.

[1] The committee feels that this section may be too conservative. However, the additional investigation necessary to determine proper design methods requires more time than has been available.

(*b*) Stirrups or bent-up bars to be considered effective as web reinforcement shall be anchored at both ends, according to the provisions of Sec. 904:

803. Stirrups.—(*a*) Area of steel required in stirrup shall be computed by formula (15).

$$A_v = \frac{V's}{14000d} \qquad (15)$$

804. Spacing of Stirrups.—(*a*) Where the shearing stress is not greater than $0.06f'_c$ the distance s between two successive stirrups measured perpendicular to the direction of the stirrup shall not exceed $\frac{3}{4}d$, and where unit shearing stress exceeds $0.06f'_c$, it shall not be greater than $\frac{3}{8}d$.

805. Bent-up Bars.—(*a*) Where there is a series of parallel bent-up bars at varying distances from the support, they shall be considered as inclined stirrups and the area required determined from formula (15).

(*b*) Where bent-up bars in a single plane are used for web reinforcement, the required area of the bar shall be computed by formula (16).

$$A_v = \frac{V'}{16000 \sin \alpha} \qquad (16)$$

(*c*) In formula (16), V' shall not exceed $0.035f'_c\,bd$ nor α be less than 15 deg. Only the center three-fourths of the inclined portion of such bar or group of bars shall be considered effective in resisting shear. Between the face of the support and the area reinforced by the bent-up bar, other web reinforcement shall be provided, except that when the distance is less than $d/2$ and the beam is designed for uniform load only, such additional reinforcement need not be provided.

806. Combined Web Reinforcement.—(*a*) Where two or more types of web reinforcement are used in conjunction, the total shearing resistance of the beam shall be assumed as the sum of the shearing resistances computed for the various types separately. In such computations the shearing resistance of the concrete shall be included only once.

807. Shearing Stress in Flat Slabs.—(*a*) In flat slabs, the shearing unit stress on a vertical section which lies at a distance $t_1 - 1\frac{1}{2}$ in. from the edge of the column capital and parallel with it, shall not exceed the following values when computed by formula (14) (in which d shall be taken as $t_1 - 1\frac{1}{2}$ in.):

(1) $0.03f'_c$ when at least 50 per cent of the total negative reinforcement passes directly over the column capital;

(2) $0.025f'_c$ when 25 per cent of the total negative reinforcement passes directly over the column capital (which is the least that shall be permitted);

(3) For intermediate percentages, intermediate values of the shearing unit stress shall be used.

(*b*) In flat slabs, the shearing unit stress on a vertical section which lies at a distance of $t_2 - 1\frac{1}{2}$ in. from the edge of the dropped panel and parallel with it shall not exceed $0.03f'_c$ when computed by formula (14) (in which d shall be taken as $t_2 - 1\frac{1}{2}$ in.). At least 50 per cent of the cross-sectional area of the negative reinforcement in two column strips must be within the width of strip directly above the dropped panel.

808. Shear and Diagonal Tension in Footings.—(*a*) The shearing unit stress computed by formula (14) on a vertical section, which lies at a distance d from the face of the supported column or pier and parallel with it, shall not exceed $0.02f'_c$ for footings with straight bars, nor $0.03f'_c$ for footings in which the bars are anchored at both ends by adequate hooks or otherwise specified in Sec. 903.

(*b*) In footings supported on piles, the critical section for diagonal tension shall be considered the distance $d/2$ from the face of the column or pedestal and any piles whose centers are at or within this section shall be excluded in computing the shear.

CHAPTER 9

BOND AND ANCHORAGE

901. Computation of Bond Stress in Beams.—(*a*) Where reinforcement is used to resist tensile stresses developed by beam action, the bond stress shall be taken as not less than that computed by formula (17).

$$u = \frac{8V}{7\Sigma o d} \qquad (17)$$

(*b*) For continuous or restrained members, the critical section for bond for the positive reinforcement shall be assumed to be at the point of inflection, that for the negative reinforcement shall be assumed to be at the face of the support, and at the point of inflection. For simple beams, or at the outer ends of freely supported end spans of continuous beams, the critical section for bond shall be assumed to be at the face of the support.

(*c*) Bent-up longitudinal bars which, at the critical section, are within a distance $d/3$ from horizontal reinforcement under consideration may be included with the straight bars in computing Σo.

902. Ordinary Anchorage Requirements.—(*a*) Tensile negative reinforcement in any span of a continuous, restrained, or cantilever beam, or in any member of a rigid frame, shall have a length of anchorage beyond the face of the supporting member sufficient to develop the full maximum tension at an average bond stress not greater than $0.04f'_c$, for plain bars, or $0.05f'_c$ for deformed bars. Within any such span, not less than one-third of the negative reinforcements shall extend along the tension side of the beam at least to or beyond the point of inflection, and any bars not so extended shall be bent down at an angle of not more than 45 deg. with the axis of the member and made continuous with the positive reinforcement or anchored in a region of compression.

(*b*) Of the positive reinforcement in continuous beams, not less than one-fourth the area shall extend at the same face of the beam into the support to provide an embedment of ten or more bar diameters beyond the face of the support.

(*c*) For non-continuous beams not less than one-half the area of positive reinforcement shall extend at the same face of the beam into the support to provide an embedment of ten or more bar diameters.

903. **Special Anchorage Requirements.**—(*a*) Where increased shearing or bond stresses on account of special anchorages are permitted as specified in Sec. 306, anchorage of all reinforcement as required in Sec. 902 shall be increased to conform with the requirements of (*b*), (*c*), (*d*), and (*e*) of this section.

(*b*) In continuous and restrained beams, anchorage beyond points of inflection of at least one-third the area of the negative reinforcement and beyond the face of the support of at least one-third the area of the positive reinforcement, shall be provided to develop one-third of the allowable working stress in tension at average bond stresses not to exceed $0.04f'_c$ for plain bars nor $0.05f'_c$ for deformed bars.

(*c*) In footings, all bars shall be anchored by means of hooks at the end of the bar. The total length of bar shall be the width of the footing plus 20 bar diameters. The outer face of the hook shall not be less than 3 in. nor more than 4 in. from the face of the footing.

(*d*) In simple beams, or at the outer ends of freely supported end spans of continuous beams, at least one-half of the tensile reinforcement shall extend along the tension side of the beam to provide an anchorage beyond the face of the support for one-third of the allowable working stress in tension at an average bond stress not to exceed $0.04f'_c$ for plain bars, nor $0.05f'_c$ for deformed bars.

(*e*) In cases where the design of unusual members involves the use of unit-shearing stresses in excess of $0.09f'_c$, values up to $0.12f'_c$ may be used, providing the requirements of this section are fully met, that the members in which these stresses are used shall be specially designed on the plans and that these members shall be constructed under the personal supervision of the designing engineer who shall notify the commissioner of buildings at least one day in advance of the placing of the concrete in such member. When required by the commissioner of buildings, the designing engineer shall submit an affidavit certifying that he has personally supervised the construction of these members and that the design and construction was in all respects as called for on the plans and in conformity with the provisions of this code.

904. **Anchorage of Web Reinforcement.**—(*a*) Web reinforcement shall be anchored at both ends by one of the following methods or combination thereof, but only anchorage meeting the requirements of (1), (2) or (3) shall be used for shearing unit stresses in excess of $0.08f'_c$.

(1) Providing continuity with the main longitudinal reinforcement.

(2) Bending around the longitudinal bar or steel shape;

(3) A hook which has a radius of bend not less than four times the diameter of the web bar;

(4) A length of embedment sufficient to develop the stress in the stirrup by bond as provided below, provided also that the other end of the stirrup is anchored as in (1).

(*b*) The end anchorage of a web member not bearing on the longitudinal reinforcement shall be such as to engage an amount of concrete sufficient to prevent the bar from pulling out. In all cases the stirrups shall be carried as close to the upper and lower surfaces as fireproofing requirements permit.

(*c*) The stress in a stirrup or web reinforcement bar shall not exceed a value equal to the surface area of the bar embedded within the upper or lower one-half of the beam multiplied by $0.04f'_c$ for plain bars, or $0.05f'_c$ for deformed bars, except that when wire fabric is used for web reinforcement it shall have welded intersections not farther apart than 6 in., but in no case shall the stress exceed 16,000 lb. per sq. in.

CHAPTER 10

FLAT SLABS

(Two-way and Four-way Systems with Square or Rectangular Panels)

1001. **Limitations.**—(*a*) The term flat slabs as used in these regulations refers to concrete slabs, having reinforcement bars extending in two or four directions, without beams or girders to carry the load to supporting members.

(*b*) The moment coefficients, moment distribution, and slab thicknesses specified herein are for a series of slabs of approximately uniform size arranged in three or more rows of panels in each direction, and in which the ratio of length to width of panel does not exceed 1.33.

(*c*) Slabs with paneled ceiling or with dropped panels shall be considered as coming under the requirements herein given, provided the dropped panel shall have a length or diameter in each direction parallel to a side of the panel of not less than 0.35 of the panel length in that direction, and provided further that the depth of the thicker portion of the slab does not exceed one and one-half times the depth of the remainder of the slab.

(*d*) For structures having a width of less than three rows of panels, or in which irregular panels are used, an analysis shall be made of the moments developed in both slabs and columns. When so required, computations shall be submitted to the commissioner of buildings for approval.

1002. **Panel Strips and Principal Design Sections.**—(*a*) For convenience of reference, a flat slab panel shall be considered as consisting of strips as follows:

A *middle strip* one-half panel in width symmetrical with respect to the panel center line and extending through the panel in the direction in which moments are being considered;

A *column strip* one-half panel in width occupying the two quarter panel areas outside of the middle strip.

When considering moments in the direction of the width of the panel, the panel is similarly divided by strips, the widths of which are each one-half the length of the panel.

(*b*) The critical sections for moment calculations are referred to as principal design sections and are located as follows:

Sections for Negative Moment.—These shall be taken along the edges of the panel, on lines joining the column centers, and following the circumference of the column capital.

Sections for Positive Moment.—These shall be taken on the center line of the panel.

1003. Moments in Interior Panels—General Case.—(*a*) The numerical sum of the positive and negative moments in the direction of either side of a rectangular panel shall be not less than that given by formula (19).

$$M_o = 0.09Wl\left(1 - \frac{2c}{3l}\right)^2 \qquad (19)$$

Where M_o = sum of positive and negative bending moments at the principal design sections, in the direction in which the length is given by l. This moment is in foot-pounds when c and l are in feet and W is in pounds.

(*b*) The moments in the principal design sections shall be those given in the following table of moments, except that the maximum negative moment in the column strip may be greater or less than the values given in the table of moments by not more than $0.03M_o$, provided that the sum of the moments on the principal section remains equal to M_o, and provided further that the moment in each of the three other critical design sections be modified by not more than $0.01M_o$.

MOMENTS TO BE USED IN DESIGN OF FLAT SLABS

For Interior Panels Fully Continuous

General case: all values of c: M_o given by Formula (19)

Strip	Flat slabs without dropped panels		Flat slabs with dropped panels	
	Negative	Positive	Negative	Positive
Slabs with 2-way reinforcement				
Column strip	$-M_c = 0.46M_o$	$+M_c = 0.22M_o$	$-M_c = 0.50M_o$	$+M_c = 0.20M_o$
Middle strip	$-M_m = 0.16M_o$	$+M_m = 0.16M_o$	$-M_m = 0.15M_o$	$+M_m = 0.15M_o$
Slabs with 4-way reinforcement				
Column strip	$-M_c = 0.50M_o$	$+M_c = 0.20M_o$	$-M_c = 0.54M_o$	$+M_c = 0.19M_o$
Middle strip	$-M_m = 0.10M_o$	$+M_m = 0.20M_o$	$-M_m = 0.08M_o$	$+M_m = 0.19M_o$

(*c*) The width of section at the column head shall be taken as the width of the dropped panel where used or half the width of panel where no dropped panel is used.

(*d*) The band width in the two-way system shall be such as to provide reinforcement over the entire one-half panel width.

(*e*) The band width for the direct bands in the 4-way system shall be approximately four-tenth of the panel width at right angles to the direction of the band ($0.4l_1$) and for the diagonal bands approximately 0.4 of the average span length. In proportioning the reinforcement in this system, it shall be assumed that reinforcement in the direct band resists the entire positive moment for the column strip and the two diagonal bands resist the entire positive moment for the column strip and the two diagonal bands resist the entire positive moment for the middle strip. Reinforcement for negative moment for the column strip shall include the area of reinforcement for negative moment in the diagonal bands multiplied by the cosine of the angle between the diagonal band and the axis of the direct band considered plus the full area of the reinforcement for negative moment in the direct band. The negative reinforcement for the middle strip shall be provided independently of the diagonal bands.

1004. Moments in Interior Panels—Special Case, c = 0.225 Times the Average Span Length.—(*a*) For the particular case where c is equal to 0.225 times the average span length (the average of the distances center to center of columns on the two sides of the panel), formula (19) reduces to formula (19*a*).

$$M_o = 0.065Wl \qquad (19a)$$

(*b*) For two-way slab, the values of M_o may be obtained from formula (19*a*) and the distribution taken from the table in Sec. 1003(*b*).

(*c*) For the four-way slab with dropped panel, the following table of coefficients may be used in computing the reinforcement required in each of the bands, provided that l for the direct bands shall be the center to center distance

between columns in the direction in which the band extends, and for the diagonal bands the average value of l for the two direct bands of the panel. The moments in the table are those on *sections at right angles* to the direction of the respective bands:

Band	Location	Amount
Direct	Center	$+0.012Wl$
Diagonal	Center	$+0.009Wl$
Direct	At column head	$-0.020Wl$
Diagonal	At column head	$-0.011Wl$
Top band across direct band	Between columns	$-0.005Wl$

1005. Thickness of Slabs and Dropped Panels.—(*a*) For slabs without dropped panels, using concrete of 2000 lb. per sq. in. ultimate strength, the total thickness of the slab t_1, in inches, shall be not less than the value given by formula (20).

$$t_1 = 0.038\left(1 - 1.44\frac{c}{l}\right)l\sqrt{w'} + 1\tfrac{1}{2} \qquad (20)$$

where w' = uniformly distributed dead and live load, lb. per sq. ft.

(*b*) For slabs with dropped panels, using concrete of 2000 lb. per sq. in. ultimate strength, the total thickness in inches at points beyond the dropped panel shall be not less than

$$t_2 = 0.02l\sqrt{w'} + 1 \qquad (21)$$

(*c*) The dropped panel shall have a thickness not greater than $1.5t_2$ nor less than $1.25t_2$. The side or diameter of the dropped panel shall not be less than 0.35 times the side of the panel in the parallel direction.

(*d*) In determining minimum thickness by formulas (20) and (21), the value of l shall be the panel length center to center of the columns, on the long side of the panel. For concrete of 2000 lb. per sq. in. ultimate strength, the slab thickness t_1 or t_2 shall in no case be less than $l/32$ for floor slabs, and not less than $l/40$ for roof slabs.

(*e*) Where concretes of higher ultimate strengths than 2000 lb. per sq. in. are used, the thickness given by formulas (20) and (21) and the limiting thicknesses may be reduced by multiplying by the factor $\sqrt[3]{\frac{2000}{f'_c}}$, in which f'_c is the ultimate strength of the concrete to be used.

1006. Limiting Percentages of Reinforcement.—(*a*) The ratio of reinforcement for negative moment in the column strip shall not exceed the values of p calculated for balanced reinforcement, that is, the amount of reinforcement for which both the steel and the concrete are stressed to the full amount permitted by Secs. 306 and 307. Any reinforcement in excess of this amount shall not be included in the calculation. In computing the ratio of reinforcement for negative moment in the column strip, the width of section shall be taken as in Sec. 1003(*c*). In the case of four-way design, the steel area shall consist of the area of steel for negative moment as defined in 1003(*e*).

(*b*) The ratio of flat slab reinforcement in any strip shall not be less than .0025. Bars shall not be spaced farther apart than 1½ times the slab thickness.

1007. Point of Inflection.—(*a*) In the middle strip the point of inflection for slabs without dropped panels shall be assumed at a line $0.33l$ distant from the center of the span and for slabs with dropped panels $0.3l$ distant from the center of the span.

(*b*) In the column strip, the point of inflection for slabs without dropped panels shall be at a line $0.33(l - c)$ distant from the center of the panel and $0.3(l - c)$ for slabs with dropped panels.

1008. Arrangement of Reinforcement at Column Heads—Two- and Four-way Systems.—(*a*) In both two- and four-way systems, provision shall be made for securing the reinforcement in place so as to resist properly not only the critical moments, but also the moments at intermediate sections. The full area of steel required for negative moment at the column head shall be continued in the same plane close to the upper surface of the slab to the edge of the dropped panel, but in no case less than a distance $0.2l$ from the center line of column. Lapped splices shall not be permitted at or near regions of maximum stress except as described in Sec. 505.

1009. Arrangement of Reinforcement—Two-way System.—(*a*) For column strips at least four-tenths of the area of steel required at the section for positive moment in the column strip shall be of such length and so placed as to reinforce the negative moment section at the two adjacent column heads. These bars, and any other bars for negative reinforcement shall extend into the adjacent panel to a point at least $0.05l$ beyond the point of inflection. Not less than one-third of the bars used for positive reinforcement in the column strip shall extend into the dropped panel at least twenty diameters of the bar, but not less than 12 in. or in case no dropped panel is used, shall extend to within $0.125l$ of the center line of the columns or the supports. The balance of the bars for positive reinforcement in the column strip shall extend at least $0.33l$ on either side of the center line of panel.

(*b*) For the middle strip at least one-half of the bars for positive moment shall be bent up and extend over the main bands at both sides of the panel to a point at least $0.25l$ beyond the center line of columns. The location of

the bends shall be such that for a distance 0.15l for slabs with dropped panels, (or 0.125l for slabs without dropped panels), on each side of the center line of columns, the full reinforcement required for negative moment will be provided in the top face of the slab. The full reinforcement for positive moment in the middle strip shall extend in the bottom face of the slab to a point at least 0.3l on either side of the panel center line, and at least 50 per cent of it shall extend to points 0.325l on either side of the panel center line for slabs with dropped panels, or 0.35l for slabs without dropped panels

1010. **Arrangement of Reinforcement—Four-way System.**—(*a*) For direct bands, all provisions governing the placing of steel in column strips in two-way systems apply as well to the direct bands in four-way systems.

(*b*) For diagonal bands, at least four-tenths of the area of steel required at the section for positive moment shall be of such length and so placed as to reinforce the negative moment section at the two diagonally opposite column heads. These bars and any other bars for negative reinforcement shall extend into the adjoining panel to points at least 0.4l beyond a line drawn through the column center perpendicular to the direction of the band. The straight bars for positive moment in the diagonal bands shall not be shorter than the longer straight bars in the direct bands.

(*c*) For negative moment in the middle strip, the required steel shall extend not less than 0.25l on either side of the column center line.

1011. **Wall and Other Irregular Panels.**—(*a*) In wall panels and other panels in which the slab is non-continuous on one edge, the maximum positive moments on the principal design sections parallel to the discontinuous edge (reinforcement perpendicular to that edge) shall be increased by 25 per cent.

(*b*) The positive moment reinforcement perpendicular to the discontinuous edge shall extend to this edge and have an embedment of at least 6 in. in spandrel beams or columns. All negative moment reinforcement shall be bent or hooked at spandrel beams or columns to provide adequate bond resistance.

(*c*) At the wall or discontinuous edge the negative moment in the column strip shall be taken as not less than 90 per cent and in the middle strip not less than 62½ per cent of the corresponding moments for a normal interior panel as given in the table of Sec. 1003(*b*).

(*d*) Where there is a beam or a bearing wall at the center line of columns in the interior portion of a continuous flat slab, the negative moment at the beam or wall line in the middle strip perpendicular to the beam or wall shall be taken as 30 per cent greater than the negative moment specified in Sec. 1003(*b*) for a middle strip. The half column strip adjacent and parallel to and lying on either side of the beam or wall shall be designed to resist moments at least one-fourth of those specified in Sec. 1003(*b*) for a column strip. The beam or wall in such cases shall be designed to carry a uniformly distributed load equal to one-fourth of the panel load on either side in addition to the loads directly imposed upon it.

1012. **Panels with Marginal Beams.**—(*a*) In panels having marginal beam on one edge or on each of the two adjacent edges, the beam shall be designed to carry at least the load superimposed directly upon it, exclusive of the panel load. A marginal beam which has a depth greater than one and one-half times the minimum slab thickness, shall be designed to carry, in addition to the load superimposed directly upon it, a uniformly distributed load equal to at least one-fourth of the total live and dead load for which the adjacent panel or panels are designed. Slabs supported by marginal beams on opposite edges shall be designed as freely supported slabs for the entire load.

(*b*) The half column strip adjacent to and parallel with marginal beams, having a depth not greater than one and one-half times the minimum slab thickness, shall be designed to resist half the moment specified for a full column strip.

(*c*) In wall panels having exterior columns where brackets, (the faces of which make an angle with the face of the column, projected upward, of not more than 45 deg.) are used in place of capitals, the value of (c) in the direction in which the bracket extends may be taken as twice the distance from the center of the column to a point where the structural portion of the bracket is 1½ in. thick, and averaged with the value of (c) for an interior column capital in the computations for moment in formula (19). The value of (c) for column strips parallel and adjacent to a non-continuous edge of a slab where either no marginal beam is used, or where the beam used is not deeper than one and one-half times the minimum slab thickness, should be taken as equal to the width of the wall column if no bracket is used in this direction.

(*d*) The value of (c) for column strips parallel and adjacent to marginal beams having a depth greater than the thickness of the slab at the wall columns, shall, if no bracket is used in this direction, be taken as equal to the width of the wall column plus twice the difference between the depth of the beam and the depth of the slab through the dropped panel. This value of c is to be used in calculating the $-M_c$ and $+M_c$ for the half column strip parallel and adjacent to the marginal beams only. This half column strip should be designed to resist a moment at least one-fourth as great as that specified for a column strip in the Table of Moments.

(*e*) It shall be permissible to omit the dropped panels at wall columns provided the design complies with the requirements of Sec. 1003(*b*) and 1006(*a*) for slabs without dropped panels.

1013. **Opening in Flat Slabs.**—(*a*) Openings of any size may be cut through the floor in the area common to two intersecting middle strips, provided the total positive and negative resisting moments be maintained as required in Sec. 1003(*b*) and that these total positive and total negative moments be redistributed between the remaining principal design sections to meet the new conditions.

(*b*) In any area common to two column strips, not more than one opening shall be allowed and the greatest dimension of such an opening shall not exceed 1/20l.

(*c*) In any area common to one column strip and one middle strip, openings shall not interrupt more than one-quarter of the bars in either strip and the equivalent of the bars so interrupted shall be provided by extra steel on both sides of the opening.

(*d*) Any opening larger than described above shall be completely framed on all sides with beams to carry the loads to the columns.

CHAPTER 11

REINFORCED-CONCRETE COLUMNS AND WALLS

1101. **Limiting Dimensions.**—(*a*) Unless designed as long columns under the provisions of Sec. 1108, reinforced-concrete columns shall not be longer than eleven times the least lateral dimension. Principal columns in buildings shall have a minimum diameter or thickness of 12 in. Posts that are not continuous from story to story shall have a minimum diameter or thickness of 6 in.

1102. **Unsupported Length of Columns.**—(*a*) The unsupported length of reinforced-concrete columns shall be taken as:

(1) In flat-slab construction the clear distance between the floor and under side of the capital;

(2) In beam-and-slab construction, the clear distance between the floor and the under side of the shallowest beam framing into the column at the next higher floor level;

(3) In floor construction with beams in one direction only, the clear distance between floor slabs;

(4) In columns supported laterally by struts or beams only, the clear distance between consecutive pairs (or groups) of struts or beams, provided that to be considered an adequate support, two such struts or beams shall meet the column at approximately the same level and the angle between the two planes formed by the axis of the column and the axis of each strut respectively is not less than 75 deg., nor more than 105 deg.

(*b*) When reinforced-concrete brackets are used at the junction of beams or struts with columns, the clear distance between supports may be considered as reduced by the depth of the bracket, provided the width of the bracket is at least equal to that of the beam and not less than one-half of the column.

1103. **Design of Spiral Columns.**—(*a*) The permissible axial load on columns reinforced with longitudinal bars and closely spaced spirals enclosing a circular core, shall not be greater than that determined by formula (22).

$$P = A_c[1 + (n - 1)p]f_c \qquad (22)$$

in which A_c is the area within the outer circumference of the spiral hooping, and the values of f_c are as given in Sec. 306, or as may be found for intermediate values of p by interpolation, or in general, by the formula,

$$f_c = [300 + (0.10 + 4p)f'_c] \qquad (22a)$$

(*b*) The longitudinal reinforcement shall consist of at least six bars of minimum diameter of ½ in., and of an effective cross-sectional area not less than 0.01, nor more than 0.06 of that of the core. The number of longitudinal bars concentrated in the ring at the periphery of the core shall be governed by the spacing requirements of Sec. 504(*a*). If all the bars cannot be placed at the periphery of the core, the bars within shall be stayed at intervals of 24 in., and shall not be nearer to the outer ring than two-tenths times the core diameter. When the ratio of reinforcemenat in a spirally reinforced column is greater than 0.04, special placing drawings illustrating the proper distribution of steel shall be submitted with the detail plans. Splices in longitudinal reinforcement shall provide a lap of at least 24-bar diameters for deformed bars, and 30 diameters for plain bars.

(*c*) The ratio of the spiral reinforcement shall be not less than one-fourth the ratio of the longitudinal reinforcement. Spiral reinforcement shall consist of evenly spaced continuous spirals held firmly in place and true to line by at least three vertical spacer bars. At the ends of all spirals and at points of splice, the outside diameter shall be maintained. The spacing of the spirals shall not be greater than one-sixth of the diameter of the core and in no case more than 3 in.

(*d*) Reinforcement shall be protected everywhere by a covering of concrete cast monolithic with the core which shall have a minimum thickness of 1½ in.

1104. **Design of Columns with Lateral Ties.**—(*a*) The permissible axial load on columns reinforced with longitudinal bars and separate lateral ties shall not be greater than that determined by formula (23):

$$P = 0.225f'_cA_g[1 + (n - 1)p] \qquad (23)$$

(*b*) The ratio of longitudinal reinforcement shall not be less than 0.005 nor shall the ratio considered in the calculations be more than 0.02 of the total area of the column. The longitudinal reinforcement shall consist of not less than four bars of minimum diameter of ⅝ in., placed with clear distance from the face of the column not less than 2 in., nor more than 3 in. Splices in longitudinal reinforcement shall provide a lap of at least 24-bar diameters for deformed bars, and 30 diameters for plain bars.

(*c*) Lateral ties shall be at least ¼ in. in diameter spaced not more than 12 in. apart. In columns of rectangular section, cross ties shall be arranged to afford support to the vertical bars at intervals not greater than the shorter side of the section, but such interval need not be less than 12 in. in any case.

1105. **Bending in Columns.**—(*a*) The bending moments in interior and exterior columns shall be determined on the basis of loading conditions and end restraint, and shall be provided for in the design.

(*b*) In flat-slab construction, the least dimension of the column shall be not less than one-fifteenth of the average center to center span, nor less than 16 in. For known eccentric loads or unequal spacing of columns, computations of moments shall be made accordingly. Wall columns in flat-slab construction shall be designed to resist a bending moment of $Wl/35$. Any counter moment due to the weight of the structure that projects beyond the column center line may be deducted from the moment computed as just described. Resistance to the bending moments shall be divided between the columns immediately above and below in direct proportion to the values of their ratios of I/h (see Secs. 709 and 1102).

(*c*) The recognised methods shall be followed in calculating the stresses due to combined axial load and bending. The column section shall not be less than that required where axial load alone is considered. The limiting combined unit stresses shall be as follows:

(1) Columns with spiral reinforcement, $[300 + (0.10 + 4p)f_c'] + 0.15f'_c$.

(2) Columns with lateral ties $0.3f'_c$. The total amount of reinforcement considered in the computations shall not be more than 4 per cent of the total area of the column.

(3) Tension in longitudinal reinforcement due to bending on the column shall not exceed 16,000 lb. per sq. in.

(d) Where the allowable unit stress in columns is increased (to provide for combined axial load and bending) and wind loads are also added, the total shall still come within the allowable values specified for wind loads in Sec. 604.

1106. Composite Columns.—(a) The permissible load on composite columns in which a structural steel or cast-iron column is thoroughly encased in a concrete core reinforced with not less than 0.02 nor more than 0.04 longitudinal reinforcement in the form of bars arranged at the periphery of the core, nor less than 0.01 of spiral reinforcement meeting the requirements for spirals of Sec. 1103(c), shall be based on a certain unit stress for the steel or cast-iron section plus a unit stress of $0.25f'_c$ on the net area of the concrete within the outer circumference of the spiral hooping enclosing the core. The longitudinal and spiral reinforcement ratios stated shall be based on the total core area enclosed within the outer circumference of the spiral hooping.

(b) The unit compressive stress on the steel section shall not exceed 15,000 lb. per sq. in. Where the steel section is required to carry construction or other loads prior to its encasement in concrete, the stress shall not exceed that given by formula (24).

$$f_r = \frac{18,000}{1 + \frac{h^2}{18,000R^2}} \qquad (24)$$

(c) The unit stress on the cast-iron section shall not exceed 9000 lb. per sq. in. Where the cast-iron section is required to carry construction, or other loads prior to its encasement in concrete, the stress shall not exceed that given by formula (25).

$$f_r = 12,000 - 60\frac{h}{R} \qquad (25)$$

(d) The unit stress on the longitudinal reinforcement shall be $0.25nf'_c$.

(e) The diameter of the cast-iron section shall not exceed one-half the diameter of the core, nor shall its total area exceed 12 per cent of the core area, (area included within outer circumference of the spiral hooping). The dimension of the structural steel section shall be such as to provide at least 3 in. between the spiral and the corners of the section and its area shall not exceed 12 per cent of the core area. Metal columns shall be accurately milled at splices and positive provision shall be made for alignment of one column above another. The spiral reinforcement shall be not less than 0.01 of the volume of the care, and shall conform in quality, spacing, and other requirements to the provisions for spirals in Sec. 1103(c).

(f) In composite columns, provision shall be made at the base to transfer the load from the middle section at safe unit stresses in accordance with Sec. 1205. The base of the metal section shall be designed to transfer the load from the entire composite column to the foundation, or it may be designed to transfer the load from the metal section only, provided it is so placed in the pier or pedestal as to leave ample section of concrete above the base for the transfer of the load from the reinforced-concrete section of the column by means of bond on the vertical reinforcement, and by direct compression from the concrete. At the top of the metal section, provision shall be made to receive the full load to be transferred to the metal section at this point. At points in the structure below this, where the load on the metal section is increased, positive means, consisting of cast or built-up brackets rigidly attached to the metal section, shall be provided to receive the increase in load.

(g) Ample section of concrete and continuity of reinforcement shall be provided at the junction with beams or girders. The area of the concrete between the spiral and the metal column shall be not less than that required to carry the total floor load of the story above on the basis of a stress in the concrete of $0.35f'_c$, unless special brackets are arranged on the metal column to receive directly the beam or slab load.

1107. Combination Columns.—(a) Structural steel columns of any rolled or built-up section wrapped with the equivalent of No. 8 U. S. standard gage wire spaced 4 in. on center and encased in concrete not less than 2 in. thick over all of metal except rivet heads and connections will be permitted to carry a load equal to $(1 + A_c/100A_s)$ times permissible load for unencased steel columns.

(b) The permissible load for unencased steel columns shall be determined by formula (24), provided the structural steel columns acting independently of the concrete shall have sufficient capacity to carry all dead loads which will be placed thereon, and provided the quality of the concrete is such that it shall show a compressive strength of at least 2000 lb. per sq. in. at 28 days when tested in accordance with Sec. 201(c).

1108. Long Columns.—(a) The permissible working load on the core in axially loaded spiral or composite columns which have a length greater than 50 times the least radius of gyration of the column core (50R) shall not be greater than that determined by formula (26).

$$\frac{P'}{P} = 1.50 - \frac{h}{100R} \qquad (26)$$

(b) The permissible working load on axially-loaded tied columns, which have a length greater than 40 times the least radius of gyration of the column section (40R), shall not be greater than that determined by formula (26a).

$$\frac{P'}{P} = 1.33 - \frac{h}{120R} \qquad (26a)$$

(c) The radius of gyration of a column shall be computed from the concrete area used in design and the transformed section of the longitudinal steel area; that is, the actual area of steel multiplied by n.

1109. Monolithic Walls.—(a) Reinforced-concrete *bearing* walls shall have a thickness of at least one twenty-fifth ($\frac{1}{25}$) of the unsupported height or width, provided, however, that approved buttresses, built-in columns, or

piers designed to carry all the vertical loads, may be used in lieu of greater thicknesses. Working compressive stresses in such walls shall not exceed $0.0625f'_c$ when the wall is 25 times the thickness in height, increasing proportionately to $0.125f'_c$ when the wall is 15 times the thickness or less in height.

(*b*) The lateral support for such walls shall consist of a fire-resistive floor when the framing is on one side of the wall only, but may be of a fire-resistive or of a non-fire-resistive type where framing is on both sides of the wall, provided that for residences, wood-frame construction properly tied may be used as support.

(*c*) In fire-resistive buildings, reinforced-concrete *bearing* walls shall have a thickness at least equal to the values shown in the table of minimum wall thicknesses given at the end of this section, except that exterior basement walls shall not be less than 8 in. thick.

(*d*) In fire-resistive buildings, bearing walls shall be reinforced with an area of steel in each direction, vertical and horizontal, at least equal to 0.0025 times the cross-sectional area. Walls 8 in. or more in thickness shall have half the steel at each face of the wall. The bars shall not be farther apart in either direction than 18 in., regardless of whether the steel is disposed in one or two layers, nor shall less than the equivalent of 3/8-in. round bars be so used. The vertical steel shall not be relied on to carry load unless tied and arranged as in reinforced-concrete columns.

(*e*) All bearing walls shall be designed for any lateral pressure to which they are subjected. Eccentric loads and wind stresses shall be fully provided for. In such designs, the stresses for flexure as given in Sec. 306 shall govern.

(*f*) In non-fire-resistive buildings, exterior bearing walls may be of reinforced concrete, subject to the provisions of this section, when increased 50 per cent in thickness over those referred to in (*c*). In such walls, the amount of reinforcement in each direction, horizontal and vertical, shall be at least 0.002 times the cross-sectional area. The steel shall be distributed half to each face of the wall with a maximum bar spacing of 24 in.

(*g*) In buildings of skeleton construction, panel or other walls supported on the structural frame shall not be less than 5 in. thick, nor less than one-thirtieth (1/30) of the horizontal distance between columns, cross walls, or equivalent anchorage. Such walls shall be reinforced in the same manner as bearing walls in fireproof buildings, (see (*d*) above).

(*h*) Stairway and elevator enclosures in all classes of buildings may be built of reinforced concrete, when the wall thicknesses are in accordance with the requirements of (*c*) and (*g*) and reinforcement in accordance with (*d*).

MINIMUM WALL THICKNESS, IN INCHES, IN STORY INDICATED

No. of stories	Basement	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
1	6	6									
2	7	6	6								
3	8	7	7	6							
4	8	8	7	7	6						
5	9	8	8	7	7	6					
6	9	9	8	8	7	7	6				
7	10	9	9	8	8	7	7	6			
8	10	10	9	9	8	8	7	7	6		
9	12	10	10	9	9	8	8	7	7	6	
10	12	12	10	10	9	9	8	8	7	7	6

CHAPTER 12

FOOTINGS

1201. Loads.—(*a*) Footings resting directly on soil or on piles shall be proportioned as to area or number of piles on the basis of the total column load plus the weight of the footing itself. For computations of moments and shears, an upward reaction per unit area or per pile shall be based on the total column load (not including the weight of the footing itself) divided by the area or by the number of piles.

1202. Sloped or Stepped Footings.—(*a*) Footings in which the thickness has been determined by the requirements for shear as specified in Sec. 808, may be sloped or stepped between the critical section and the edge of the footing, provided that the shear on no section outside the critical section exceeds the value specified, and provided further that the thickness of the footing above the reinforcement at the edge shall not be less than 6 in. for footings nor less than 12 in. for footings on piles. Sloped or stepped footings shall be cast as a unit.

1203. Bending in Footings.—(*a*) The critical section for bending in a concrete footing which supports a concrete column or pedestal, shall be considered to be at the face of the column or pedestal. Where steel or cast-iron column bases are used, the moment in the footing shall be computed at the middle and at the edge of the base; the load shall be considered as uniformly distributed over the column or pedestal base.

(*b*) The bending moment at the critical section in a square footing supporting a concentric square column, shall be computed from the load on the trapezoid bounded by one face of the column, the corresponding outside

edge of the footing, and the portions of the two diagonals. The load on the two corner triangles of this trapezoid shall be considered as applied at a distance from the face equal to six-tenths of the projection of the footing from the face of the column. The load on the rectangular portion of the trapezoid shall be considered as applied at its center of gravity. The bending moment is expressed by formula (27).

$$M = \frac{w}{2}(a + 1.2c)c^2 \tag{27}$$

(*c*) For a round or octagonal column, the distance a shall be taken as equal to the side of a square of an area equal to the area enclosed within the perimeter of the column.

1204. Shearing and Bond Stresses.—See Sec. 808, also Secs. 901 to 904.

1205. Transfer of Stress at Base of Column.—(*a*) The compressive stress in longitudinal reinforcement at the base of a column shall be transferred to the pedestal or footing by dowels. There shall be at least one dowel for each column bar, and the total sectional area of the dowels shall not be less than the sectional area of the longitudinal reinforcement in the column. The dowels shall extend into the column and into the pedestal or footing not less than 30 diameters of the dowel bars for plain bars, or 24 diameters for deformed bars.

(*b*) The permissible compressive unit stress on top of the pedestal or footing directly under the column shall be not greater than that determined by formula (28).

$$r_a = p_a \sqrt[3]{\frac{A}{A'}} \tag{28}$$

(*c*) The value of p_a shall not exceed $0.25f'_c$ for plain concrete. When lateral reinforcement in the form of spiral or hoops is provided, the value of p_a for the area within the spiral may be increased $(1 + 2.5np')$ times that for plain concrete, but no area outside the outer face of the spiral shall be considered. Where piers are designed as columns, the value of p_a shall be computed by the proper column design formula.

(*d*) In no case shall the total load computed by formula (28) be taken as greater than the load computed, using a stress equal to p_a, on the gross area of the pedestal, pier, or footing at a point below special reinforcing provided at the top.

(*e*) Where the loaded area is not central on the top of the pedestal pier, or footing, the total area A shall not be taken as greater than the area of the largest circle that can be drawn about the load as a center and lying entirely within the top of the pedestal, pier, or footing.

(*f*) Where lateral reinforcement is provided to increase the value of p_a, it shall extend to within 3 in. of the top of the pedestal, pier, or footing and to a depth equal to the diameter of the spiral, and the loaded area shall lie at the center of the spiral or hoops. The pitch of the spiral or the spacing of the hoops *in the clear* shall not be less than 2 in., nor more than 5 in. The designed pitch shall be maintained by at least four spacers securely fastened to each spiral turn or hoop. The ratio of lateral reinforcement shall not exceed 0.015.

(*g*) In sloped or stepped footings, A may be taken as the area of the top horizontal surface of the footing or as the area of the lower base of the largest frustum of a pyramid or cone contained wholly within the footing and having for its upper base the loaded area A', and having side slopes of 1 vertical to 2 horizontal.

1206. Pedestals without Reinforcement.—(*a*) The allowable compressive unit stress on the gross area of a concentrically loaded pedestal or on the minimum area of a pedestal footing shall not exceed $0.25f'_c$, unless reinforcement is provided and the member designed as a reinforced-concrete column.

(*b*) The depth of a pedestal or pedestal footing shall not be greater than three times its least width and the projection on any side from the face of the supported member shall not be greater than one-half the depth. The depth of a pedestal whose sides are sloped or stepped shall not exceed three times the least width or diameter of the section midway between the top and bottom. A pedestal footing supported directly on piles shall have a mat of reinforcing bars having a cross-sectional area of not less than 0.20 sq. in. per ft. in each direction, placed 3 in. above the top of the piles.

APPENDIX L

PROPOSED SPECIFICATIONS FOR CAST STONE AMERICAN CONCRETE INSTITUTE[1]

I. General

(1) The term "cast stone" shall be understood to mean a building stone manufactured from portland cement concrete, precast and set in place as trim or facing on or in buildings and other structures.

(2) The minimum average compressive strength of cast stone at the age of 28 days or less shall be 5,000 lb. per sq. in. when tested as 2 × 2-in. cylinders or 2 × 2-in cubes in the manner hereinafter specified.

(3) At the age of 28 days or less the average absorption of cast stone shall be not less than 3 and not more than 7 per cent of water by dry weight of the specimen when tested as 2 × 2-in. cylinders or 2 × 2-in. cubes in the manner hereinafter specified.

(4) All aggregate used in the manufacture of cast stone shall be of known durable quality.

II. Selection of Specimens for Testing

(5) Specimens for both compression and absorption tests shall be cut from stone as delivered on the job or from regular stock in the yard. Samples from which specimens will be cut shall be selected by the purchaser or his representative.

(6) Specimens of faced cast stone for compression tests shall be cut in such a manner that the specimens are composed of approximately one-half of facing and one-half of backing material. Specimens shall be tested in the position in which the cast stone is laid in the wall.

III. Methods of Testing

(7) Not less than 3 and preferably 5 specimens shall be required for each test. In the event of failure to meet requirements in the first test, the test may be repeated on a second set of specimens.

(8) Specimens for absorption test shall be dried at a temperature between 215 and 225 deg. F. until the loss in weight is not more than 0.1 per cent in 2 hr. of drying. They shall be weighed and then be submerged in water at a temperature of between 60 and 80 deg. F. for 24 hours. The specimens shall then be removed from the water, the surface water wiped off with a damp cloth and the specimens weighed. The percentage of absorption is the difference in weight divided by the dry weight of the specimen and multiplied by 100.

(9) Specimens for strength test shall be dried at a temperature of between 215 and 225 deg. F. until the loss in weight is not more than 0.1 per cent in 2 hr. of drying.

(10) If bearing surfaces of specimens for strength test are not smooth, they shall be made so by grinding. If they cannot be ground to a smooth surface they shall be capped with a mixture of ½ part portland cement and ½ part plaster of paris, which shall be allowed to harden at least 5 hr. before the test. The cap shall be formed by spreading the capping material upon a plate glass and pressing the specimen firmly on it making the cap as thin as possible.

(11) Load shall be applied through a spherical bearing block placed on top of the specimen in a vertical testing machine. The dimensions of the bearing block shall be the same, or slightly larger, than that of the test specimen.

(12) Load shall be applied uniformly and without shock. The speed of the moving head of the machine shall be not more than .05 in. per min. when the machine is running idle.

(13) Specimen shall be loaded to failure and the unit compressive strength calculated in pounds per square inch. The type of failure and appearance of specimen shall be noted.

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